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Semiannual Report 8

Covering the Period 1 October 1966 through 31 March 1967

RESEARCH-ENGINEERING AND SUPPORT FOR TROPICAL COMMUNICATIONS

By: E. L. YOUNKER G. H. HAGN H. W. PARKER

Prepared for:

U.S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY 07703

CONTRACT DA 36-039 AMC-00040(E)
ORDER NO. 5384-PM-63-91

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SRI Project 4240

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ABSTRACT

Communication research in a tropical environment is needed to develop improved equipment and techniques for use by military forces in tropical environments. This report describes Stanford Research Institute's work on SEACORE (an acronym for Southeast Asia Communication Research) during the period 1 October 1966 through 31 March 1967. Among the topics under study were:

- (1) Airborne pattern measurements of antennas in vegetation
- (2) Measurement of electrical properties of vegetation and ground
- (3) Modeling of propagation through a scattering medium
- (4) Ionospheric propagation and frequency prediction
- (5) Atmospheric radio noise.

PREFACE

The work described in this report was performed with the support, and using the facilities, of the Military Research and Development Center at Bangkok, Thailand, a joint Thai/U.S. organization. The cooperation of staff members of the Thailand Ministry of Defense, the United States Advanced Research Projects Agency, and the United States Army Electronics Command made possible the work described.

This report summarizes the technical effort conducted under Contract DA 36-039 AMC-00040(E) for the period covering 1 October 1966 through 31 March 1967. In several cases, work described has been conducted by Thai personnel assigned to the Military Research and Development Center. Readers interested in additional technical detail of the work accomplished are urged to consult the published reports listed in Sec. III for discussions of specific scientific investigations.

The operations analysis work conducted under the contract was reported separately in accordance with a special report schedule.

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I INTRODUCTION

A. HISTORICAL BACKGROUND

During World War II, United States military forces operated extensively in tropical areas, thereby gaining considerable practical experience in communication problems in tropical forest and jungle areas. The pressure of military objectives limited scientific explorations into many of the specific problems that arose, resulting in sizable gaps in our knowledge of radio communication in equatorial regions. The Military Research and Development Center (MRDC) was organized as a joint Thai/U.S. Agency to conduct research on many subjects in a tropical environment, including communication research.

In 1962, the United States Army Electronics Command (USAECOM) and Stanford Research Institute (SRI) undertook the task of establishing an electronics laboratory in Thailand to facilitate a first-hand study of tropical communication problems. The MRDC Electronics Laboratory (MRDC-EL) was officially dedicated in September 1963. Staffing of the laboratory is a joint Thai/U.S. venture, with U.S. participation largely from members of the staff of SRI.

Overall direction of the U.S. portion of the MRDC has been assigned to the Advanced Research Projects Agency (ARPA) of the Department of Defense. The ARPA actively monitors and directs the work of the USAECOM and SRI. This function is carried out in Bangkok by the ARPA Research and Development Field Unit-Thailand (RDFU-T).

B. OBJECTIVES

The purpose of the work under Contract DA 36-039 AMC-00040(E) is to perform scientific and technical investigations and to support the MRDC in the areas of tactical and tropical communications. The original objectives of this effort were to:

- (1) Establish a facility for radio communication research in Thailand.
- (2) Establish suitability of various communication techniques in the tropical environment and establish values of pertinent environmental factors.

- (3) Solve existing communication problems and provide necessary engineering data to solve future communication problems.
- (4) Conduct technical tests of appropriate off-the-shelf equipments.
- (5) Analyze and evaluate these tests and recommend areas for future effort.
- (6) Formulate the equipment requirements to accomplish the task of field communication in the jungle, based upon existing and anticipated tactical requirements.
- (7) Train the Thai personnel assigned to the Electronics Laboratory so that they can utilize the facility, accomplishing this training as a natural course of operating the laboratory.
- (8) Aid those electronics projects in Thailand that appear especially useful to MRDC basic objectives and that enhance the scientific development of Thailand.

The task structure for accomplishing these objectives has necessarily changed during the progress of the work, but the basic objectives have been essentially constant during the several years of effort under this contract.

II SCIENTIFIC AND TECHNICAL INVESTIGATIONS

A. SCOPE

The project effort is concerned with radio communication in Southeast Asia. Support is furnished to the MRDC in the investigation and solution of radio communication problems in Thailand; however, most efforts are applicable to equatorial (or tropical) zone communication in general. Military communications with Thailand are typically medium-distance point-to-point communications or short-distance contact between a base station and mobile patrol. These operations take place in many types of terrain and vegetation.

The VHF band may be used for short-distance paths where the signal attenuation due to terrain features or dense intervening forest is not too great; HF skywave communication is used for path lengths beyond VHF capabilities or for short paths in heavy forest or mountainous areas.

Unique questions arise from the use of HF for short skywave paths and the use of HF and VHF in heavily forested areas, as well as from the special military problems encountered in Southeast Asia. In particular, the high radio noise level in Thailand due to tropical thunderstorm activity and the influence of proximity to the magnetic equator on ionospherically propagated waves are important factors related to the use of HF radio equipment. Furthermore, the effects of heavy forest on HF and VHF antennas and propagation have a significant bearing on the operation of equipment in these frequency ranges. Generally, these questions involve optimizing frequency allocation, radio set design, and tactical usage of equipment in this special environment.

To study such problems, several related research areas are being investigated. These are specified by the current Technical Guidelines (dated 20 May 1966) as follows:

1. Task A--Antenna Environment and Antenna System Investigations
 - (a) Subtask a--Airborne Xeledop Studies
 - (b) Subtask b--Ionospheric Sounder Studies on Commonly Used Field-Type Antennas

- (c) Subtask c--Theoretical Models of Antennas in Forests
- (d) Subtask d--Manpack Xeledop Work and Related Studies

2. Task B--Ionospheric and Frequency Spectrum Investigations

- (a) Subtask a--Ionospheric and Frequency Predictions for Bangkok
- (b) Subtask b--Faraday Rotation Studies
- (c) Subtask c--Radio Noise Studies
- (d) Subtask d--Anomalous Ionospheric Reflections Studies
- (e) Subtask e--Oblique Sounder Studies

3. Task C--System Test Format and Procedure Investigations

- (a) Subtask a--Survey of Military Testing Facilities

B. WORK ACCOMPLISHED DURING THE REPORTING PERIOD

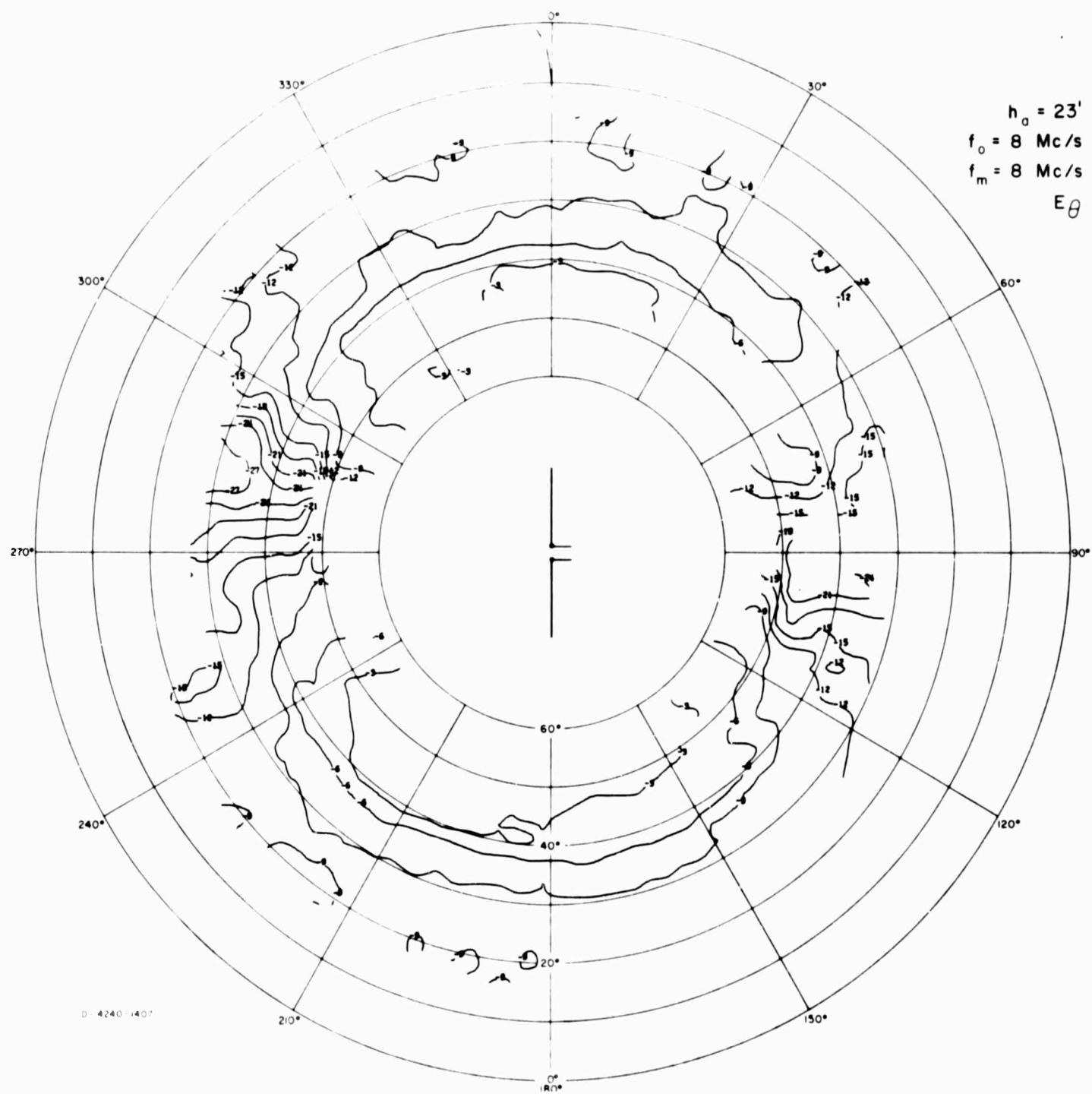
1. Task A: Antenna Environment and Antenna System Investigations

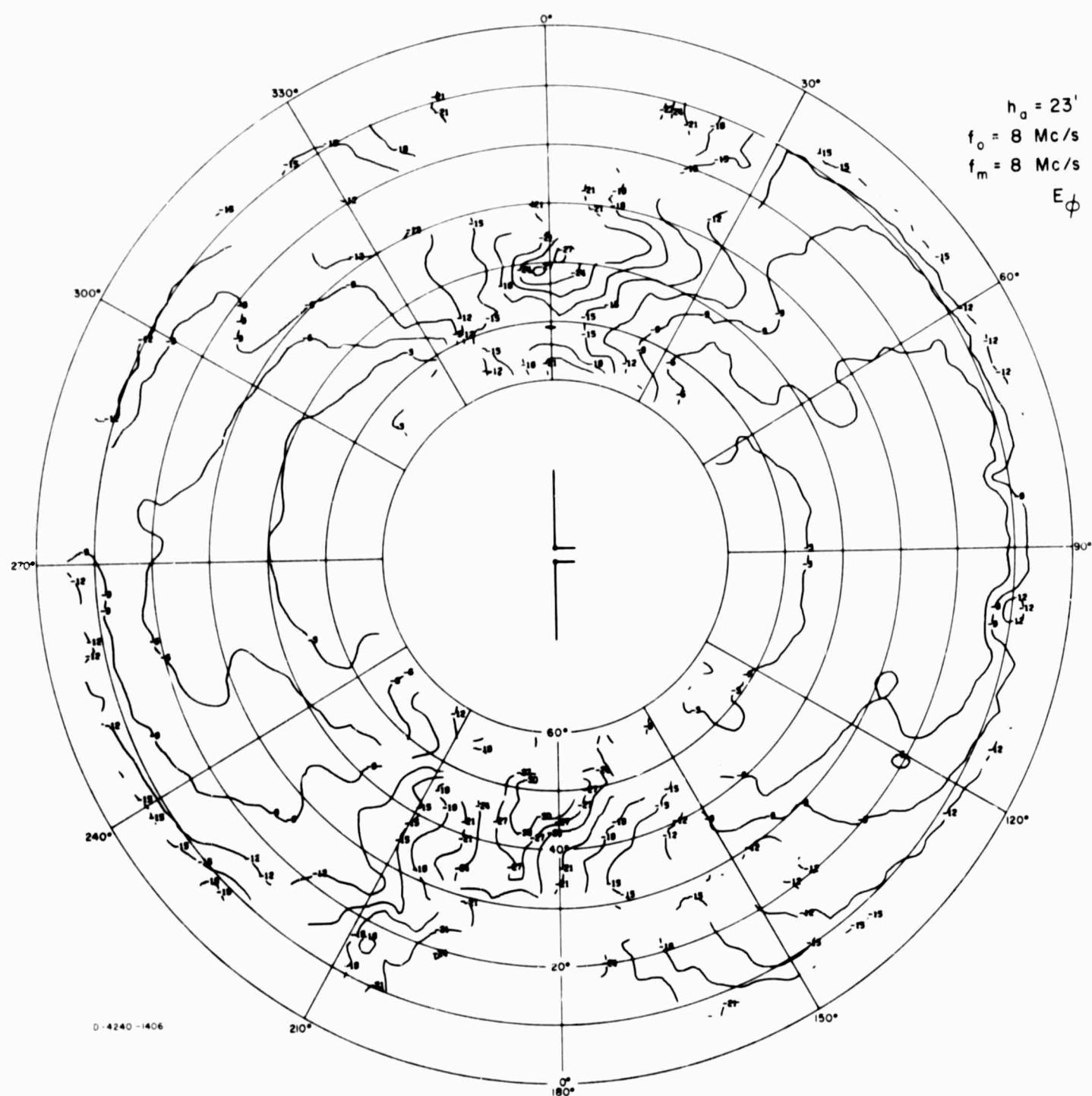
- (a) Airborne Xeledop Studies

The major effort on this task during the reporting period was processing the data obtained at Ban Mun Chit during the previous reporting period.

(1) HF Measurements

Processing of the HF data recorded on analog chart recordings has progressed favorably to produce stereographic contour plots of the relative received signal strength as a function of azimuth and elevation angle. Contour plots of the E_ϕ (horizontal) and E_θ (vertical) polarization response of the 8-MHz, 23-ft-high unbalanced dipole are shown in Figs. 1 and 2. This antenna was erected about 350 ft inside the forest and to the same specifications as used at the previous sites. The relative gain values on the contour plots are referenced to the largest observed signal strength, which (for these dipoles) occurred during the highest orbit (highest elevation angle for which data were obtained). Therefore, the dB contours are not referenced to the maximum gain of the dipole (which should occur at the zenith). Model calculations





indicate the increase in gain from 60 degrees (near the highest orbit) to 90 degrees is only a few dB at the azimuth of maximum gain.^{1*}

One objective of the HF airborne Xeledop measurement program is to document the change in antenna performance when the same antenna structure is employed in different environments: level, open field (Lodi, California),^{2,3} U.S. conifer forest (Lake Almanor, California),⁴ and Thailand forest (Ban Mun Chit, Thailand).⁵ This is now possible for the 8-MHz, 23-ft-high, unbalanced dipole, even though the data are incomplete in places owing to loss of some data because of contamination of the records by man-made interference on the crystal-controlled Xeledop frequency.

The patterns are essentially "dipolar" in each case, although minor perturbations can be observed. The perturbations for the dipoles located in the vegetation are slightly greater than for the dipole in the clearing, and the patterns for the antennas in the vegetation display somewhat less symmetry.

A comparison of the elevation angles at which a given relative directivity occurred for the same dipole in the three different locations is given in Table I. The range of elevation angles indicated corresponds to the azimuth of maximum gain for a given polarization (i.e., broadside for horizontal polarization and end-on for vertical polarization). This elevation angle range was scaled from both main lobes of each patterns; in all three cases--for Lodi (clear), Almanor (conifers), and Ban Mun Chit (jungle)--these dB contours fall within the ranges indicated in Table I.

We noted that E_θ main lobes usually had their directivity patterns broadened out toward lower angles when going from clearing to forest; but the directivity of the E_θ main lobes was essentially unchanged when the antenna was in forest. The horizontal patterns showed more variations, especially assymmetry.

(2) VHF Measurements

Processing the magnetic tape records obtained in connection with the digitizer (used to convert the received signals to digital form and recorded on magnetic tape at the time it was taken) proved

*References are listed at the end of this report.

TABLE I
COMPARISON OF ELEVATION ANGLES
ASSOCIATED WITH A GIVEN RELATIVE GAIN IN THREE ENVIRONMENTS

Contour (dB Relative to measured maximum)	Elevation Angle Range					
	Horizontal Polarization (E_ϕ)			Vertical Polarization (E_θ)		
	Clear	Conifers	Jungle	Clear	Conifers	Jungle
- 3	40°	25°-30°	40°-45°	45°	45°-50°	40°-45°
- 6	20°	20°-25°	10°-20°	35°-40°	35°-40°	35°-40°
- 9	15°	10°-20°	5°-10°	30°-35°	30°-35°	30°-35°

more difficult than originally anticipated. Nevertheless, most of the magnetic tape records have been converted to a usable form. Scaling of analog records taken as backup was initiated for the few remaining runs.

Figure 3 is an example of signal strength received on three antennas located about 150 feet into the forest at Ban Mun Chit as a function of azimuth:

- C1 = 50-MHz vertical folded dipole
- C2 = 75-MHz horizontal unbalanced dipole
- C3 = 100-MHz vertical sleeve dipole.

Each ordinate tick represents a 10 dB change in amplitude. The feed point of these antennas was located about 10 feet above ground.

The Xeledon was oriented vertically and flown at a slant range of 4 miles and an elevation angle of 25 degrees. These plots of raw data are examples of a preliminary computer plot produced on a cathode-ray tube (CRT) display and photographed. These are used to check the data for gross errors prior to final processing. Notice the significant perturbations (nulls to greater than 20 dB) similar to those observed on similar antennas in the eucalyptus grove in California.⁶

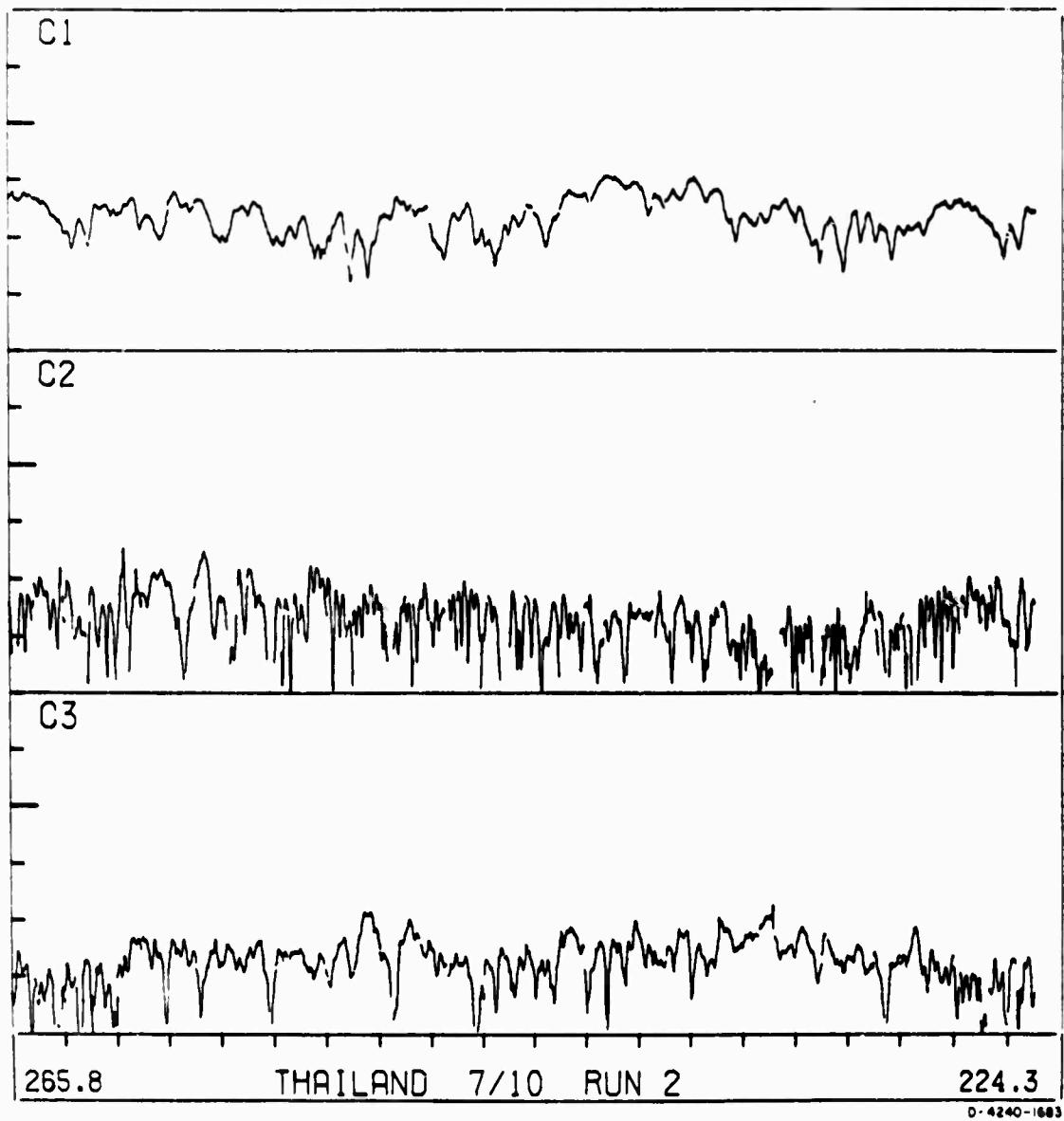


FIG. 3 SIGNAL STRENGTH AS A FUNCTION OF AZIMUTH RECEIVED BY THREE
ANTENNAS IN FOREST

b. Ionospheric Sounder Studies on Commonly Used Field Antennas

No work was done on this task during the reporting period; however, it is anticipated that this task will be completed during the next reporting period.

c. Theoretical Models of Forest Electromagnetic Effects^{*}

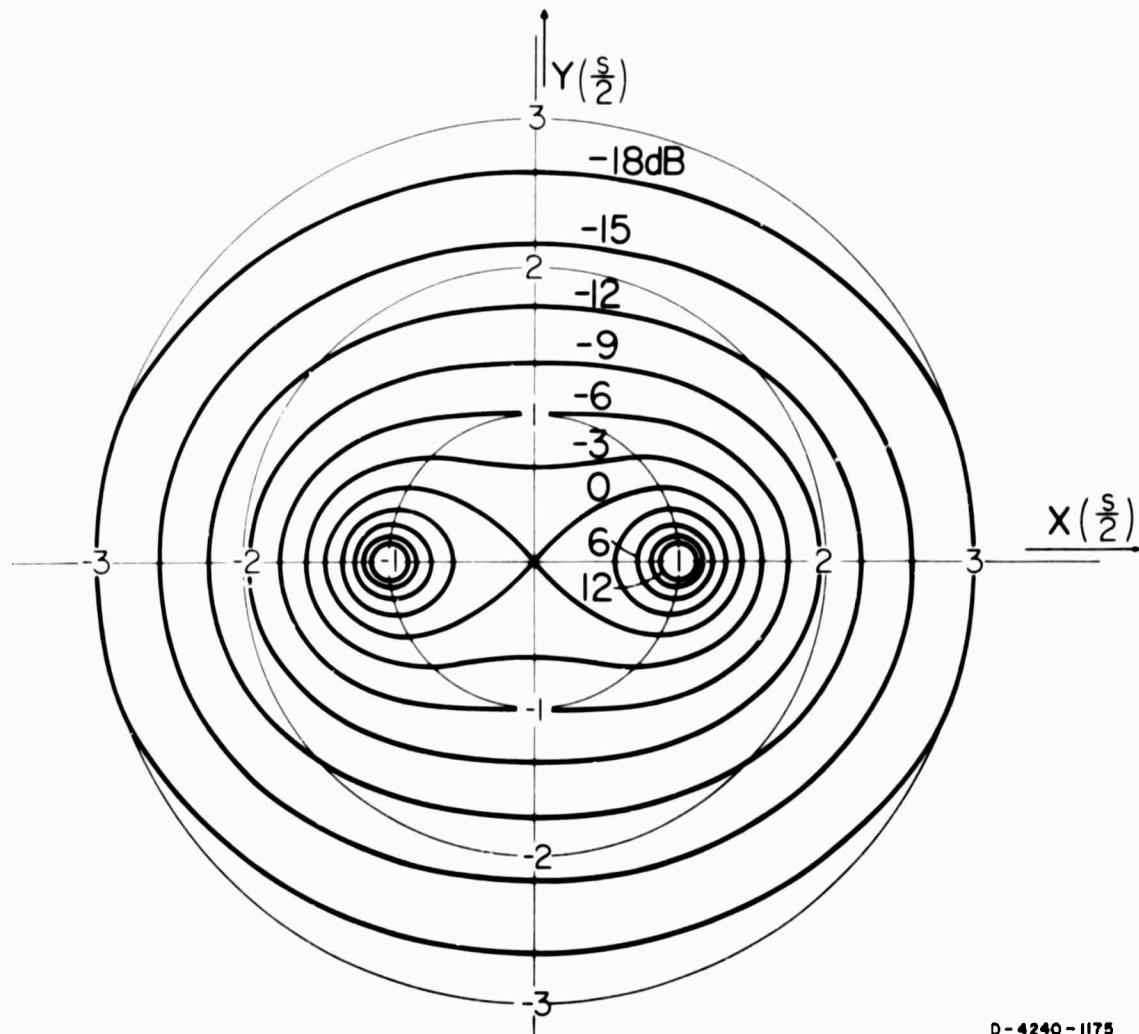
(1) General

In the use of open-wire transmission lines (OWL) to make measurements among plant stems and branches, the question arises as to what degree measurements are affected by scatterers at different distances from the OWL. Figure 4 is a plot of contours of constant power density[†] around the conductors of a 300 ohm (in air) balanced OWL. The conductors are at $X = \pm 1.0$. The values of the power contours have been normalized to that of the contour through the origin (bipolar center). Obviously the regions nearest the conductors carry the greatest power, so that scatterers there would have the greatest effect on the measurements. Theoretical work in this context has shown that more than 99 percent of the power in the transmission line mode is carried within a cylinder whose radius is three times the conductor spacing (S) centered on the origin in Fig. 4.

Using the fact that only scatterers in the immediate vicinity of the OWL (especially between the conductors) are important, and assuming trees appear as lossy dielectric cylinders, theorists at University of South Carolina have reduced the study of the scattering problem to one of finding the effects of a lossy capacitor shunting the line. The effects on open- and shorted-end impedance of a theoretical OWL have been computed under assumed conditions of random distribution of the lossy circuit elements along its length. A computer model has been written to perform the operations, based on knowledge of the statistical distributions of tree positions and

^{*} This section of the report deals with modeling work in progress at the University of South Carolina, supported under subcontract to SRI.

[†] The derivation of this power density was carried out by C. C. Han, and will be included in a Special Technical Report 42 (in preparation).



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FIG. 4 CONTOUR OF CONSTANT POWER DENSITY AROUND CONDUCTORS OF 300-ohm BALANCED OWL

sizes in a forest. The user need only specify the intrinsic electric constants of tree stems in order to calculate the equivalent lossy capacitor representing any tree at any distance from the Owl.

An experiment was performed to verify this approach by comparing predictions from the scatter model with measurements made on an Owl repeatedly surrounded by wet wooden bars whose positions (80 in all) were assigned by throwing a die. The equivalent admittances of the wooden bars (for input to the model) were measured using the Owl. Two

sizes of bars were used: 1-square-inch and 4-square-inch cross section. The results averaged for five measurement trials and ten model permutations in each case are shown in Table II.

TABLE II
COMPARISON OF CALCULATED AND MEASURED (OWL) PROPERTIES
OF A SCATTERING MEDIUM

Scatterer Cross Section (inches)	Measurement		Model Computation	
	ϵ_r	δ	ϵ_r	δ
1 X 1	1.027	0.005	1.046	0.004
2 X 2	1.108	0.010	1.130	0.013

The model obviously gave a reasonable prediction of the measurements made on an OWL placed at five positions among simulated "tree trunks." The work outlined here, together with results of further modeling studies on antennas placed in forests, which has continued at University of South Carolina, will be reported in forthcoming Special Technical Reports.*

(2) VHF Manpack Xeledop Measurements

Special Technical Report 26,⁷ covering the investigation of several types of terrain with the VHF manpack Xeledop, was prepared and submitted for approval for publication. Examples of the results of this work were given in Semiannual Report 6.⁸ One type of terrain investigated was foliaged beach, represented by an example near the Laem Chabang low-noise site. In order to check these measurements at a later time and in a different season (March rather than December), the VHF manpack Xeledop measurements on the foliaged trails were repeated and supplemented by open-wire line measurements of the electrical characteristics of the dense low shrubs

* The original three-layer slab model reported in Ref. 1 has been extended to handle an n-layer slab and the following simple antenna types in addition to the short dipole: loop, monopole.

along the trail. The data from this study are being analyzed and should provide a check of the lossy dielectric slab model for the case of propagation in undergrowth.

Preliminary work on the investigation of the effect of a single tree on the transmission of VHF signals from transmitter to receiver was reported previously.⁹ This work was continued along two lines. First, the effect of a nearby tree upon input impedance of a balanced* resonant half-wave dipole was observed by measuring the resistive and reactive components of antenna input impedance as functions of distance between the tree and the antenna. Second, the VHF manpack Xeledop was carried along prescribed paths near the tree under study and the amplitude of the signal received at a fixed receiving site was measured. Impedance and signal strength were measured at frequencies of 50, 75, and 100 MHz with both horizontal and vertical polarization. Impedance measurements were made on a large tree (about 5 ft in diameter at breast height), a small tree (about 2 inches in diameter at breast height), and a 4-inch OD aluminum mast about 20 ft high. A photograph of the experimental setup for measuring the variation in antenna impedance is shown in Fig. 5. The dipole is shown at a height of 10 ft (antenna feedpoint), vertically polarized, and very near the large tree. The antenna was supported by a stable tripod, which was moved along a level track and positioned at precise distances from the tree indicated by the stakes driven into the ground at the center rail.

Appreciable variation of the input impedance of the antenna was observed near the large tree and the aluminum mast, but the effect caused by the small tree was negligible. The variation of the resistive and reactive components of input impedance for the vertically polarized antenna at 100 MHz is shown in Fig. 6. The feedpoint of the antenna was set at 10 ft above ground (and at the beginning of the run at 14 ft from the tree), and the length of the dipole was adjusted to give zero reactive component. Only small impedance changes were observed at distances beyond about a quarter wavelength from the tree, but substantial

*Baluns manufactured by North Hills (BB1105) were used at the antenna feed points.

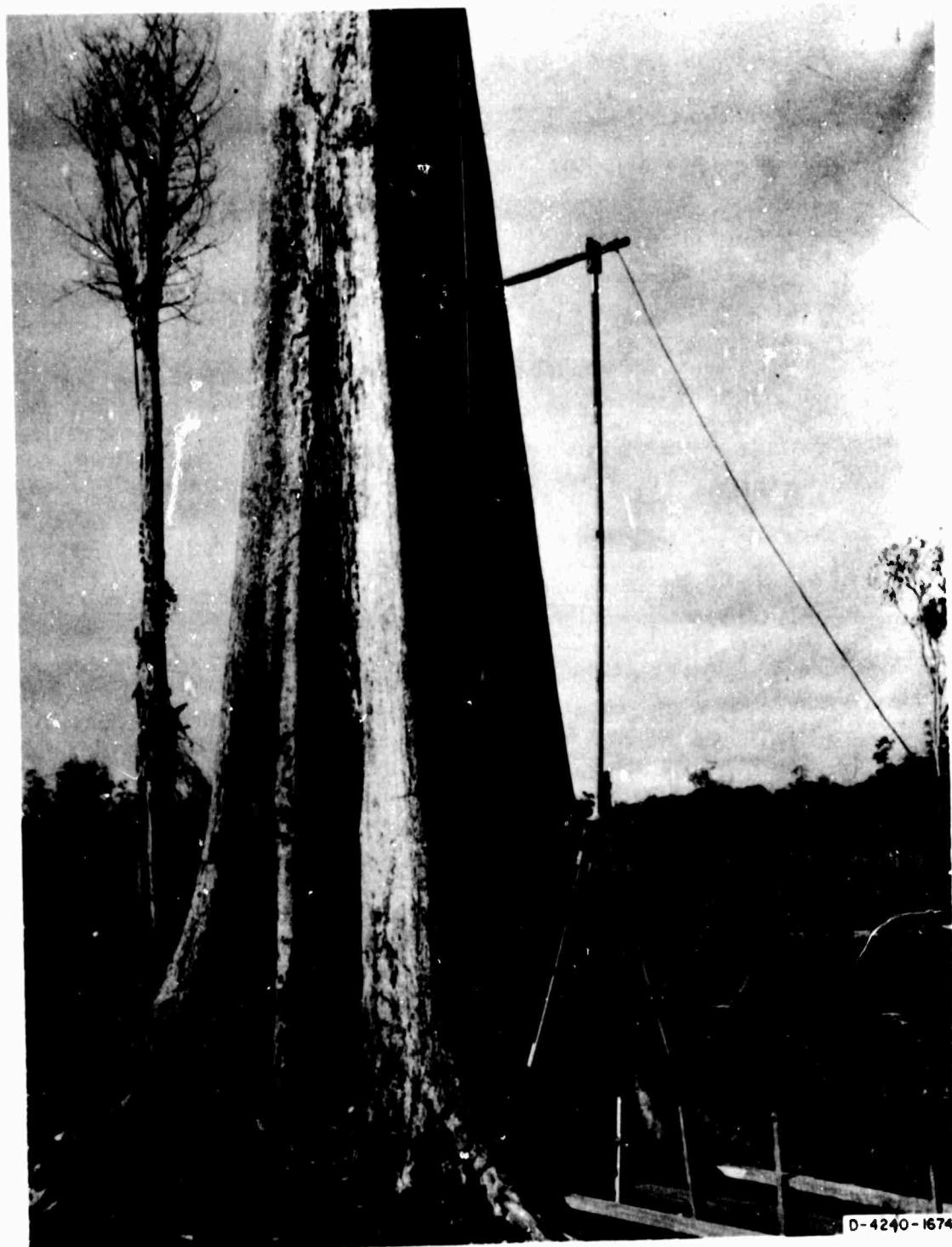


FIG. 5 EXPERIMENTAL SETUP FOR MEASURING EFFECT OF TREE ON DIPOLE IMPEDANCE

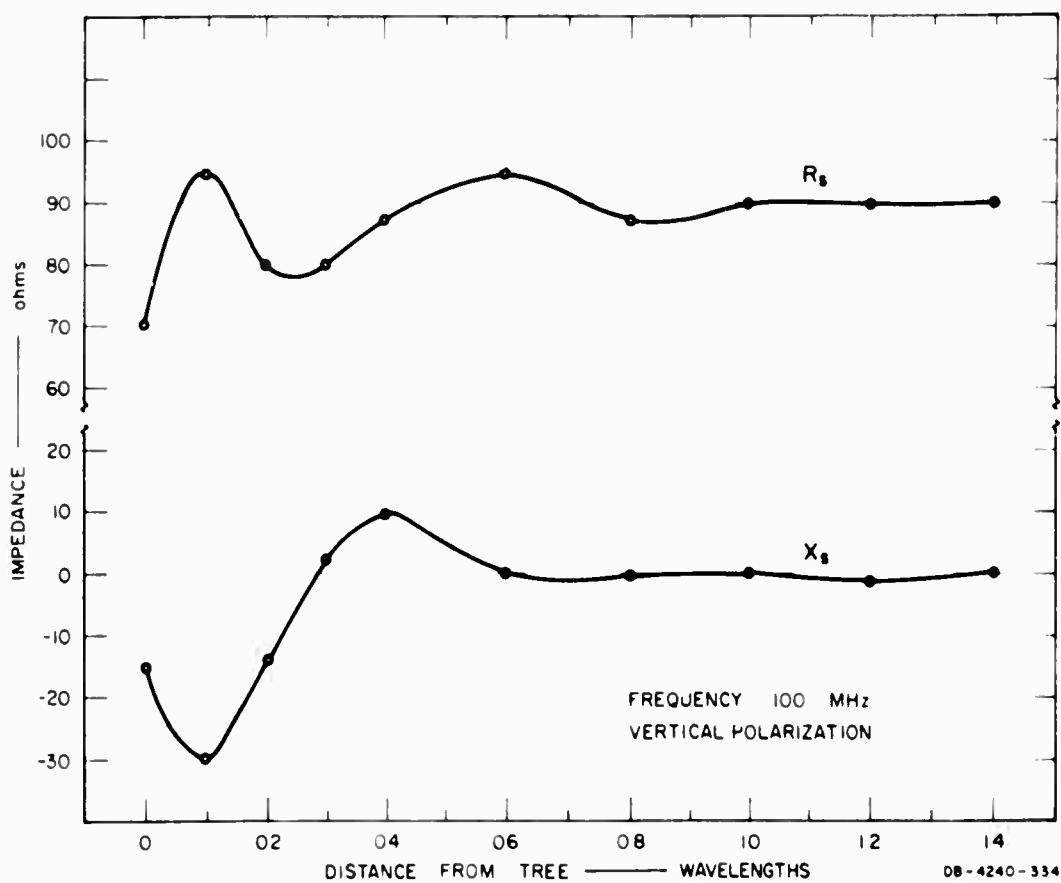


FIG. 6 VARIATION OF INPUT IMPEDANCE OF RESONANT 100-MHz DIPOLE

changes took place at distances closer to the tree. Similar measurements made with the dipole in the horizontal position showed variations having the same general characteristics and somewhat smaller amplitude. These observations indicate that, even for a large tree, changes in input impedance of the antenna as it passes at distances more than a quarter wavelength from the tree cause less than 1 dB variation in the power transmitted from the antenna of a typical VHF manpack radio. Thus the large decreases in received signal strength experienced in the forest environment are caused by other factors than detuning of the antenna.

These impedance measurements were made on trees located at the Ban Mun Chit site on the edge of the area used in the May-June 1966 airborne Xeledop measurements of radiation patterns of tactical antennas.¹⁰

An attempt to measure the effect of single trees on VHF signal propagation was then made by measuring the signal received at a point remote from a tree as the VHF manpack Xeledop transmitter was carried near the tree. The receiving antennas used in the impedance tests were also used in this experiment and the standard manpack Xeledop receiver system was employed. It was found that the null in received signal was not as large as indicated by preliminary experiments⁹ using the same tree; furthermore relatively small perturbations--such as tree stumps and unevenness of the ground--apparently tended to reduce variations in signal strength caused by the tree. Further measurements were made at a different site, where the land had recently been cleared and plowed and where all stumps and underbrush had been removed and the surface leveled (Fig. 7). More consistent results were obtained at this location but the magnitude of the tree effect was still smaller than that previously observed. These experiments show that there is some dependence of the magnitude of the single tree effect upon polarization: the larger effects occur with vertical polarization. Another interesting observation is that the metal pole produced effects similar to those for the tree on vertically polarized signals, but not for horizontally polarized signals. There was virtually no effect upon the received signal strength when the horizontally polarized Xeledop transmitter was carried past the metal pole; however, there was an observable effect nearly as large as that for vertical polarization when the horizontal Xeledop was carried past the large tree. Further work is needed in this study area.

(3) Open-Wire Line Measurements in Thailand

Considerable effort was spent in reducing the data on foliage and ground electrical characteristics obtained at the Ban Mun Chit field site during the previous reporting period.¹¹

Two computer programs have been developed in connection with the work. One accepts field measurements (impedance bridge readings) and computes open- and short-circuit impedances of the open-wire transmission line, automatically transforming past any standard connecting circuitry to the OWL input. The second accepts the computed line impedances and calculates the electrical parameters--such as dielectric constant, conductivity,

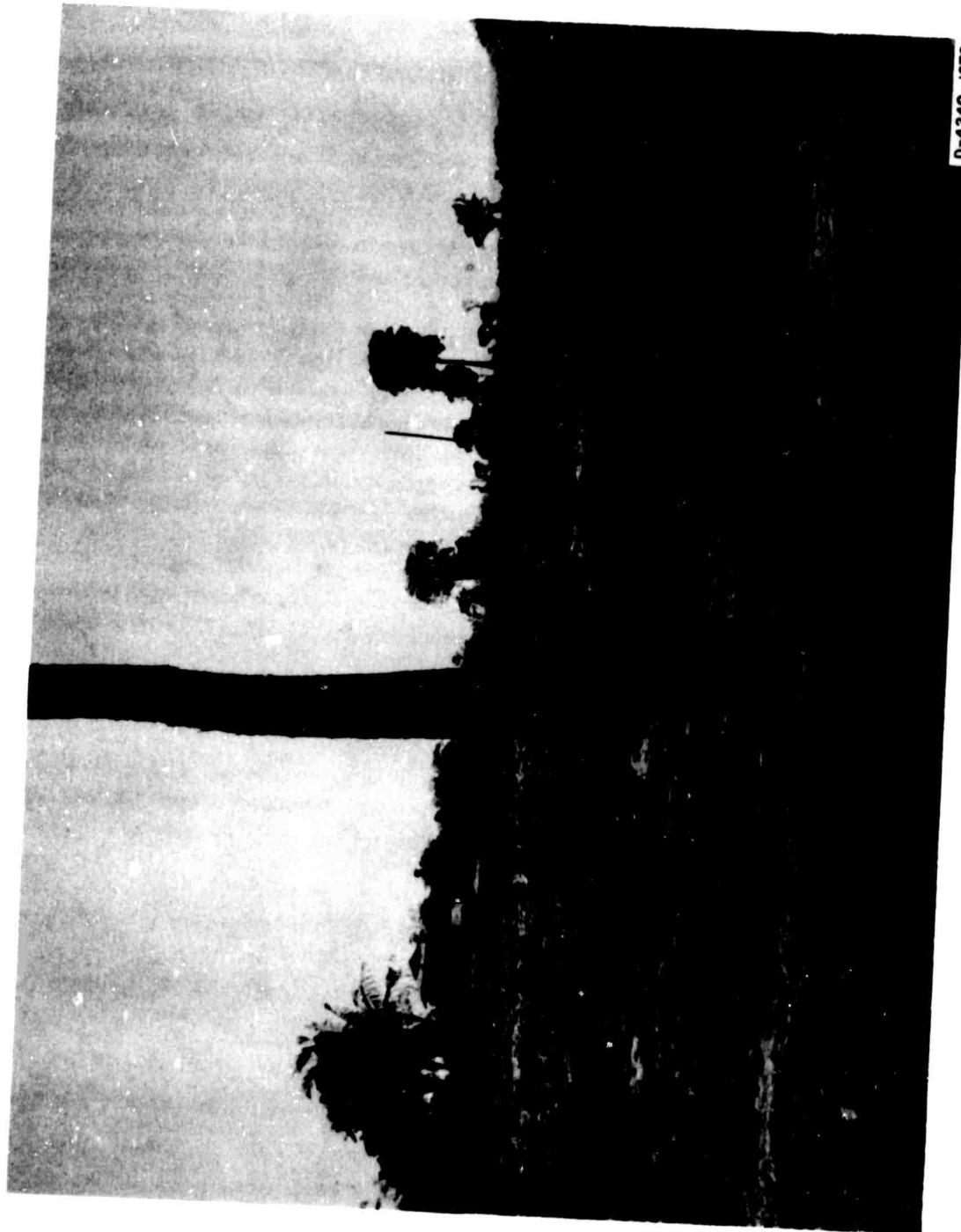


FIG. 7 VHF MANPACK XEL DOP NEAR SINGLE TREE

loss tangent, etc.--of the medium into which the line was inserted. Raw data from Ban Mun Chit for foliage considered typical of undisturbed growth between heights of 1.5 and 5 meters in semideciduous tropical forest, for an exceptionally dense volume of this foliage, and for tall tapioca plants were processed in Bangkok on an IBM 1620, which computed one numerical value for each parameter at each station measured. The validity of the results of the computation was checked and median and variance values were computed for each of the types of foliage. The results of the Ban Mun Chit foliage measurements of conductivity are summarized in Fig. 8. Significant differences can be seen between the typical undergrowth, the exceptionally dense undergrowth, and the tapioca plants.

The VHF open wire line and associated equipment were taken to the Jansky & Bailey (J&B) field site near Pak Chong for a brief series of tests (use of the site by J&B ended in September 1966) and measurements were made at a field point (FPB-1) on one of the trails used in the J&B measurements of path loss.¹² A volume of foliage typical of this field point (as well as of foliage along the entire trail) was selected with the help of members of the MRDC Environmental Sciences Division who accompanied the SRI crew. The open-wire line is shown in Fig. 9 inserted at one of the stations in this volume. The dark line running diagonally across the bottom of this photo is a small rope that was used to outline the matrix volume. Most of the measurements were made at 50, 75, and 100 MHz, but some were at 6 and 15 MHz. All measurements used the VHF open-wire line at 3-inch spacing. Median values of vegetation permittivity, conductivity, and loss tangent representing the foliage in the matrix at FPB-1 are shown in Fig. 10.

Further foliage measurements were made at the Ban Mun Chit site using the large HF version of the open-wire line. Two foliage samples were selected to be typical of the areas in which the HF and VHF antenna patterns had been measured by the airborne Xeledop technique in May and June of 1966. The HF OWL measurements were made in the 3 to 30 MHz frequency range to supplement data previously obtained with smaller VHF open-wire line. In the experiments, the length of the HF line was varied

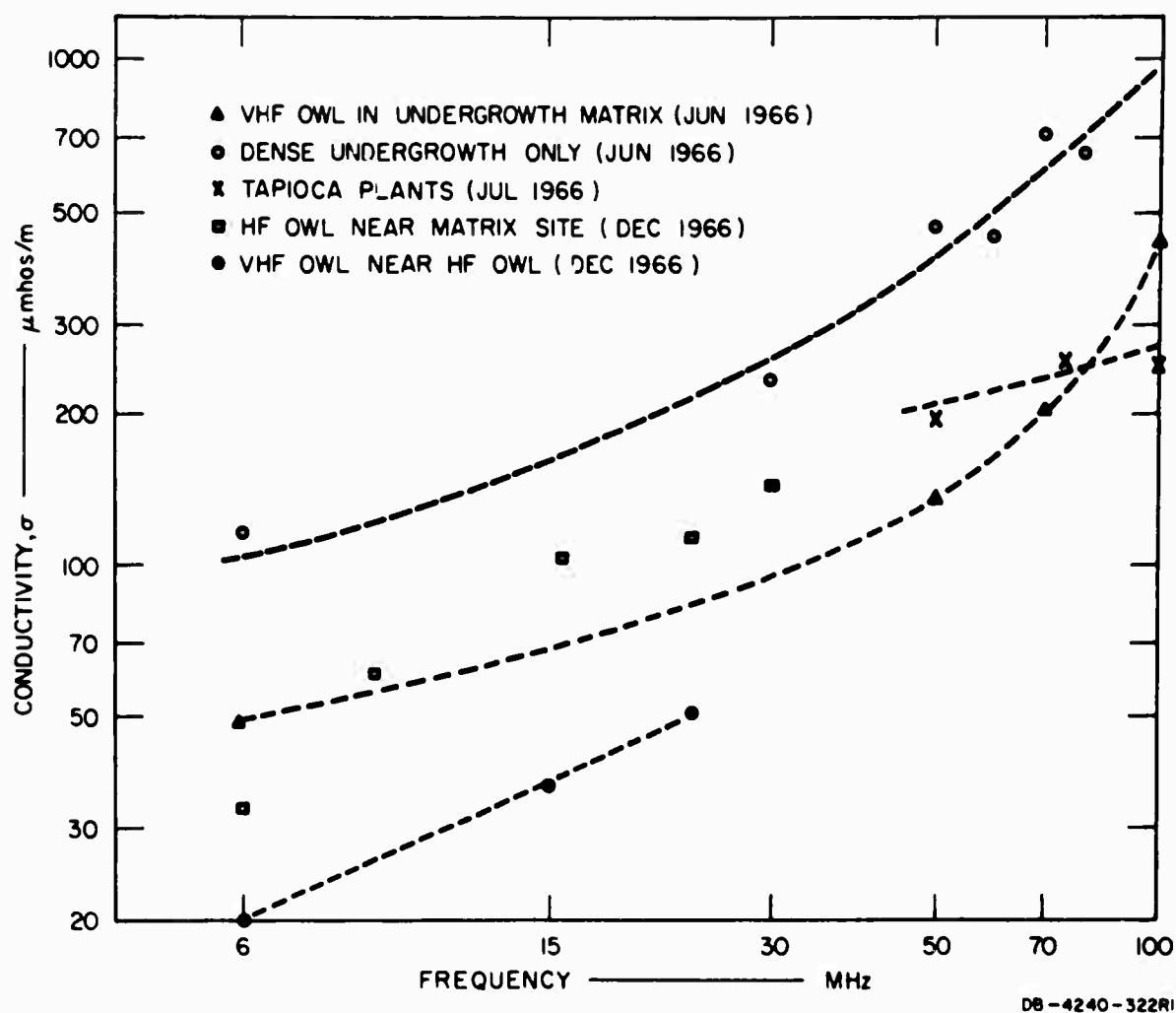


FIG. 8 CONDUCTIVITY OF FOLIAGE AT BAN MUN CHIT

in increments of 20 ft by adding lengths of the 4-inch-diameter pipe of which the transmission line was constructed. A photograph of the HF line setup for calibration in the clearing is shown in Fig. 11. The large coil of coaxial cable in the foreground is a balun for matching unbalanced impedance bridges to the balanced open-wire line.

Figure 12 shows the open-wire line immersed in foliage typical of the forest at the Ban Mun Chit site. The equipment



FIG. 9 OPEN-WIRE LINE IN FOLIAGE AT PAK CHONG

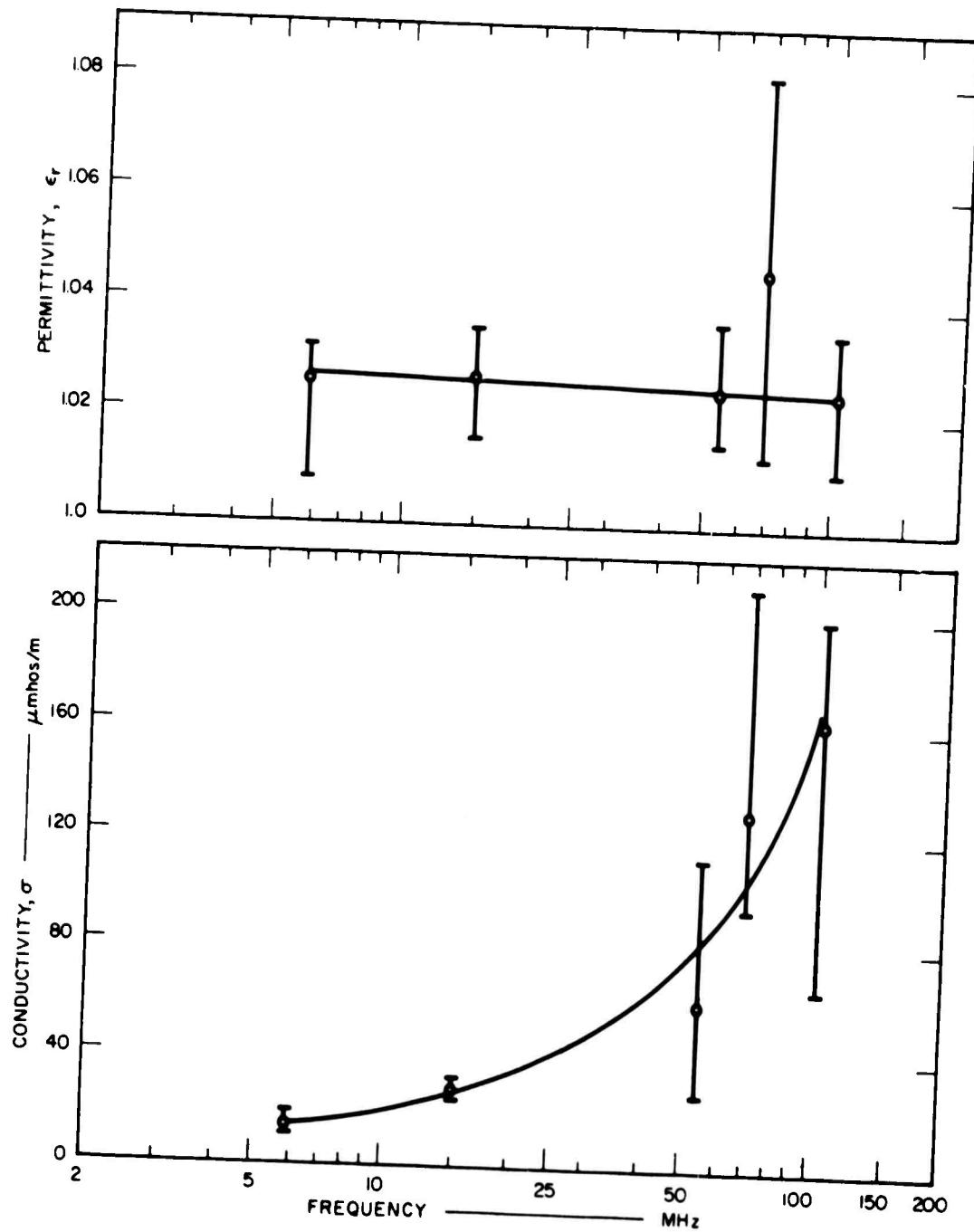


FIG. 10 ELECTRIC CONSTANTS OF FOLIAGE AT PAK CHONG

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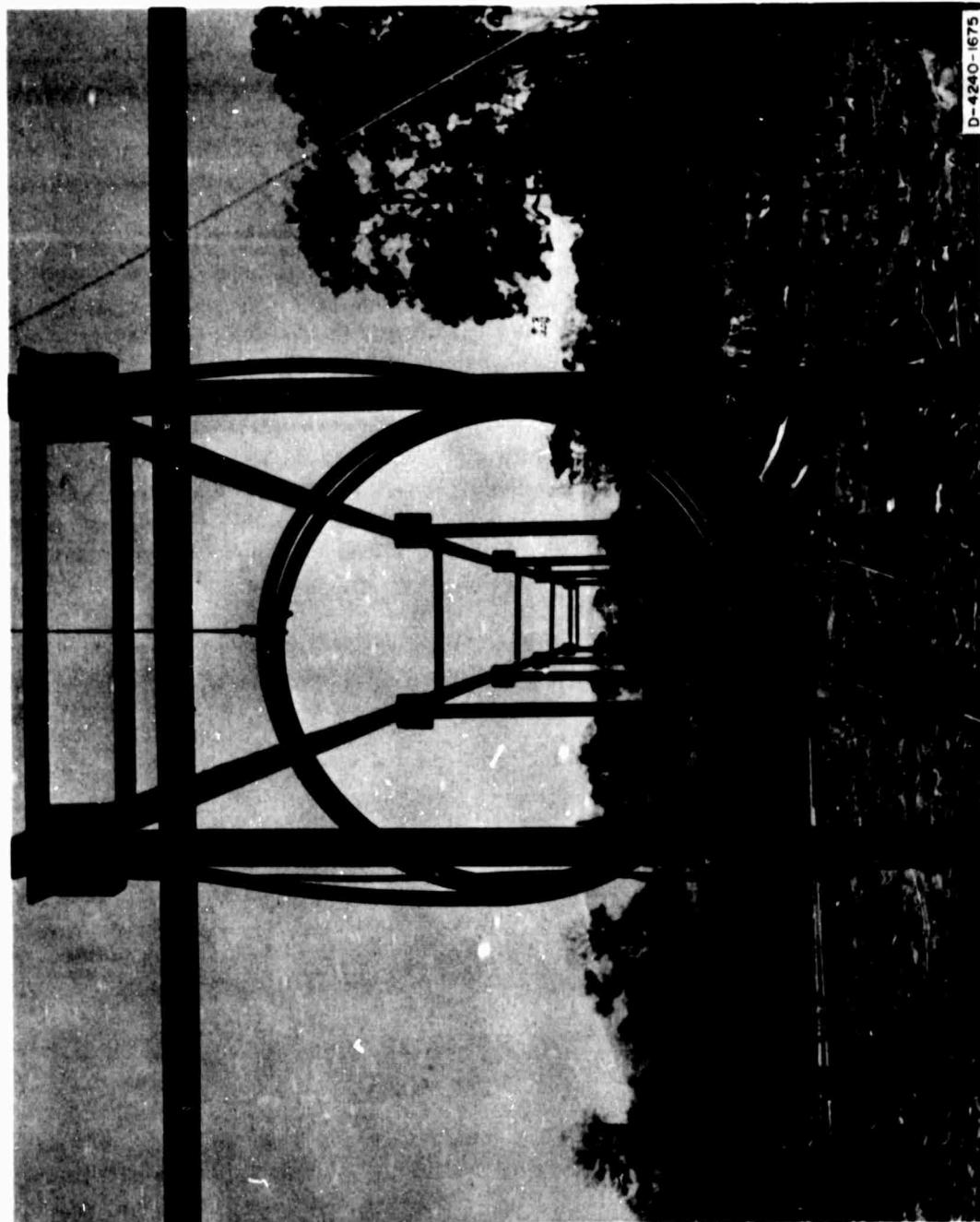


FIG. 11 HF OPEN-WIRE LINE SETUP FOR CALIBRATION AT BAN MUN CHIT



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FIG. 12 HF OPEN-WIRE LINE IMMersed IN FOLIAGE AT BAN MUN CHIT

setup for the open-wire line work is shown in Fig. 13, illustrating some of the practical difficulties of performing experimental work in a field environment. At one of the HF foliage samples, the small VHF open-wire line was used for measurements at 6, 15, and 30 MHz to allow comparison between the December HF and VHF line measurements and the VHF line measurements made in June 1966. Results are plotted on Fig. 8. The VHF OWL spacing used was 3 inches in all cases reported here; the HF OWL spacing was one meter, so that it could measure larger tree stems. The median results for both probes were fairly similar in these Ban Mun Chit data. Although June is a rainy season month, and December a drier one there, the reader is cautioned against drawing any conclusions about seasonal variation from these preliminary data.

We should stress that the measurements made with the OWL do not directly relate to either vertical or horizontal polarizations of plane waves, but lie somewhere in between. Integration of the power density in the OWL's E-field, done as part of the theoretical modeling discussed in Section C, has given information about the power contained in each of the orthogonal E-field components for a 300-ohm OWL whose conductors are in the horizontal plane. For this case, the ratio of horizontal to vertical power densities is 3/2 when the orthogonal components are summed over the entire active region of the OWL. Since the OWL was most often used in the horizontal plane, there is some bias toward measurement of the effective horizontal electric constants of anisotropic vegetation, but the true anisotropy cannot be separated out.

In conjunction with the foliage measurements at the Pak Chong site, the electrical properties of the ground were also investigated. Measurements were made at dc as well as with the open-wire line probe at several frequencies in the range 6-100 MHz. The equipment setup during an open-wire probe ground measurement is shown in Fig. 14 and the variations of conductivity and dielectric constant with frequency are given in Fig. 15.

2. Task B: Ionospheric and Frequency Spectrum Investigations

(a) Bangkok-Chanthaburi Oblique Path Experiment

During the previous reporting period an experiment¹³ was carried out to provide the basis for a comparison of vertical-incidence

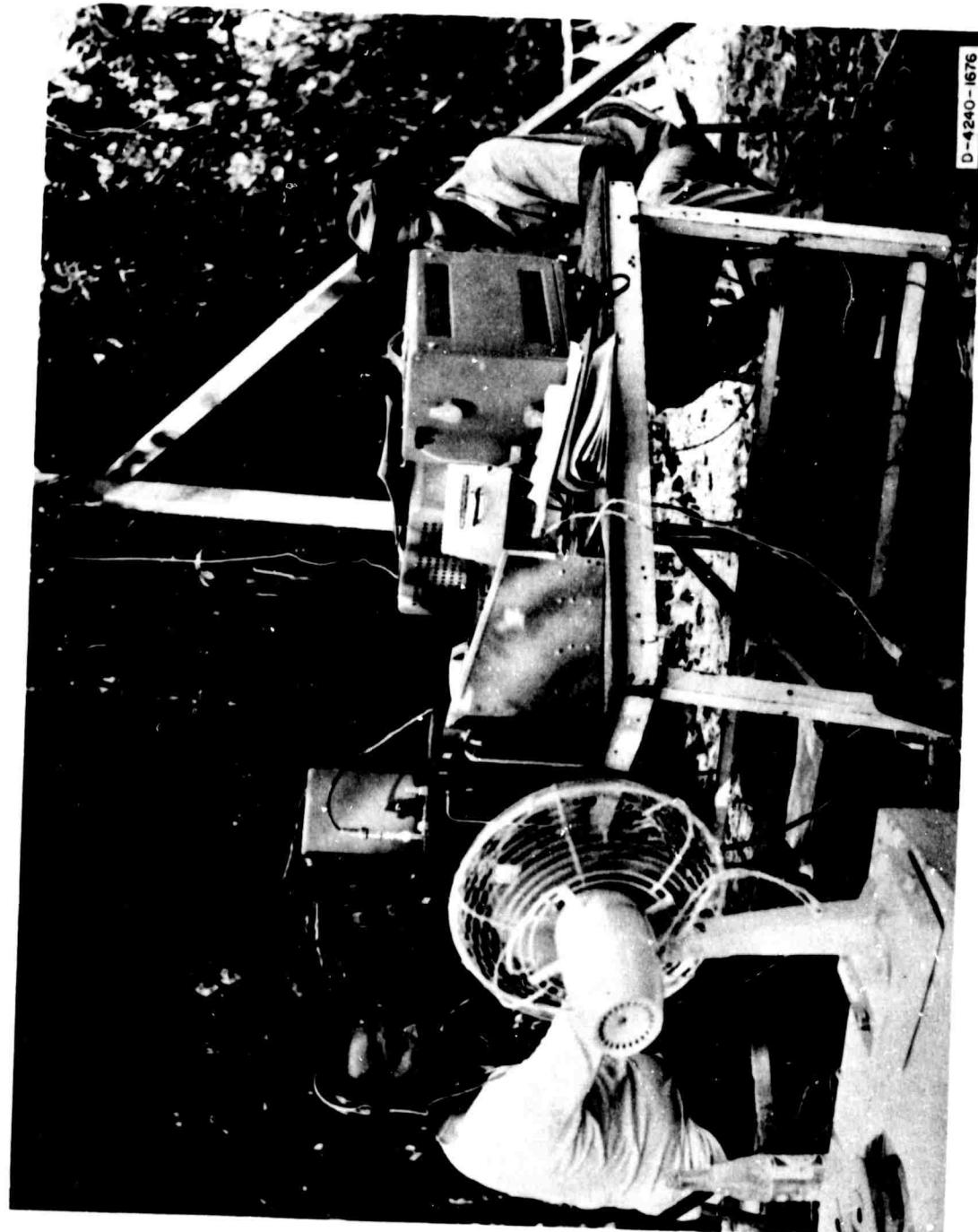


FIG. 13 VHF EQUIPMENT FOR FOLIAGE MEASUREMENTS AT BAN MUN CHIT



FIG. 14 OPEN-WIRE PROBE MEASUREMENT OF GROUND AT PAK CHONG

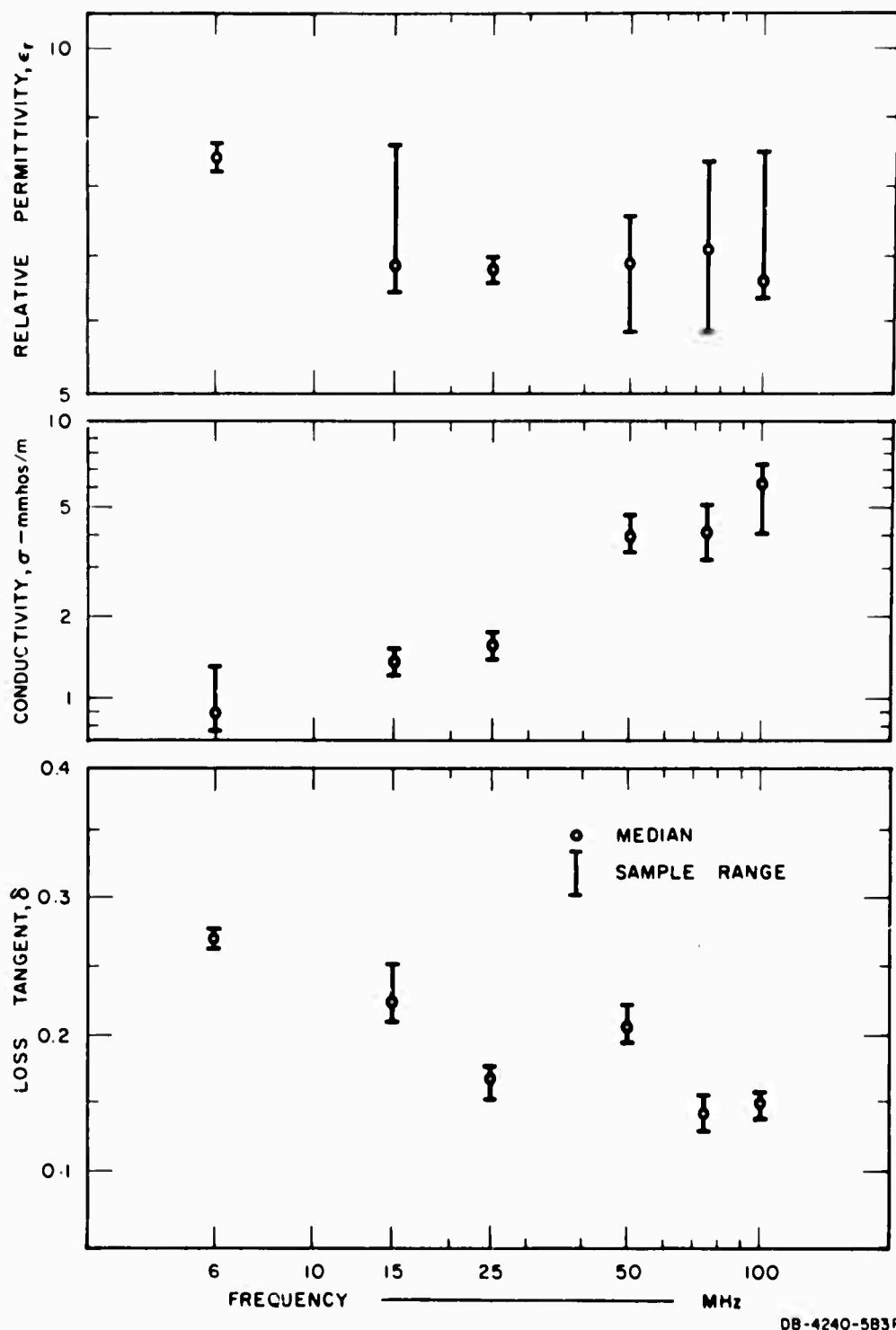


FIG. 15 PAK CHONG GROUND CONSTANTS AS A FUNCTION OF FREQUENCY

ionospheric-sounding parameters measured at Bangkok and Chantaburi and corresponding parameters measured on the oblique path between the two terminals. In this work, one Granger sounder was located at the Bangkok laboratory and the other sounder was about 200 km distant. The sounders transmitted with a frequency sweep of 4-32 MHz in a sequence which permitted the recording of vertical-incidence ionograms at Bangkok and oblique-incidence ionograms at Chantaburi, followed immediately by recording of vertical-incidence ionograms at Chantaburi and oblique-incidence ionograms at Bangkok. Scaling of the vertical and oblique-incidence ionograms obtained during the Bangkok-Chantaburi experiment was completed and medians and quartile ranges were computed for all significant parameters. The results were supplied to MRDC in computer printout format for use in analysis of equipment performance on the Chantaburi-Bangkok path. One of the most significant results of this work is illustrated by Fig. 16, which shows median value of the F2 critical frequency measured at Bangkok, the F2 critical frequency measured on the oblique path between the two sites.* The two vertical-incidence critical frequency curves are nearly identical, with a median difference of 0.2 MHz. The difference between the vertical-incidence critical frequency and the MOF is somewhat larger, but generally is less than 0.5 MHz. This shows that the vertical-incidence measurements made at Bangkok can be used to predict the Maximum Usable Frequency (MUF) for vertical-incidence skywave paths near Chantaburi and the MUF on oblique paths between Bangkok and points in the vicinity of Chantaburi.

The characteristics of sporadic E measured at the terminals and on the oblique path are shown in Figs. 17 and 18. The three curves of Fig. 17 show that Sporadic E was observed between about 0700 and 1900 hours with an upper frequency limit extending to 6-8 MHz. The percentage of occurrence of Sporadic E at Chantaburi, at Bangkok, and on the oblique path is shown in Fig. 18.

*No data are presented between 0300 and 0600 hours in Fig. 16. During this interval the critical frequency often dropped below 4 MHz, the lower limit of measurement of the Granger sounder; and the quantity of data was too small to calculate a reliable median.

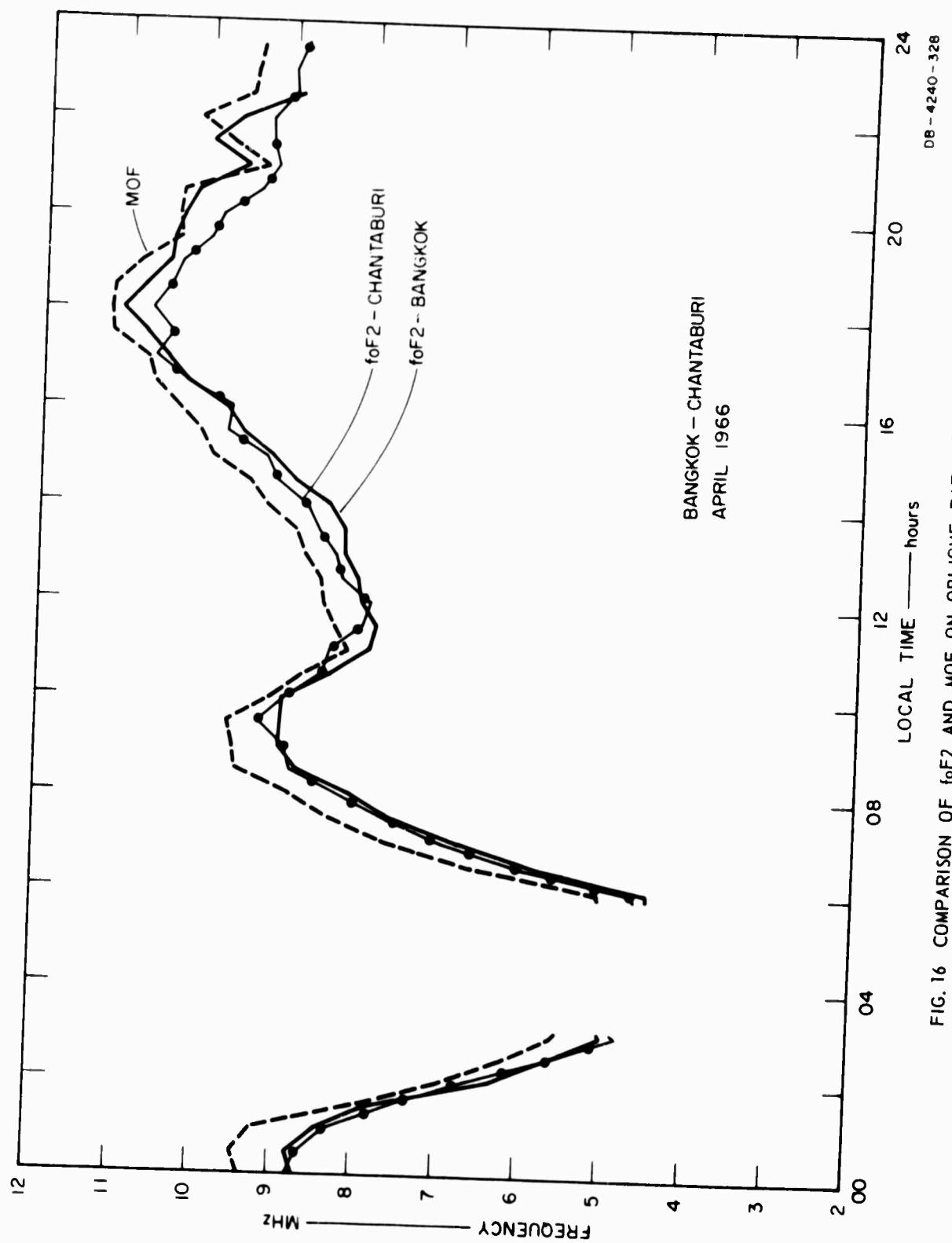


FIG. 16 COMPARISON OF f_0F2 AND MOF ON OBLIQUE PATH (Bangkok-Chanthaburi)

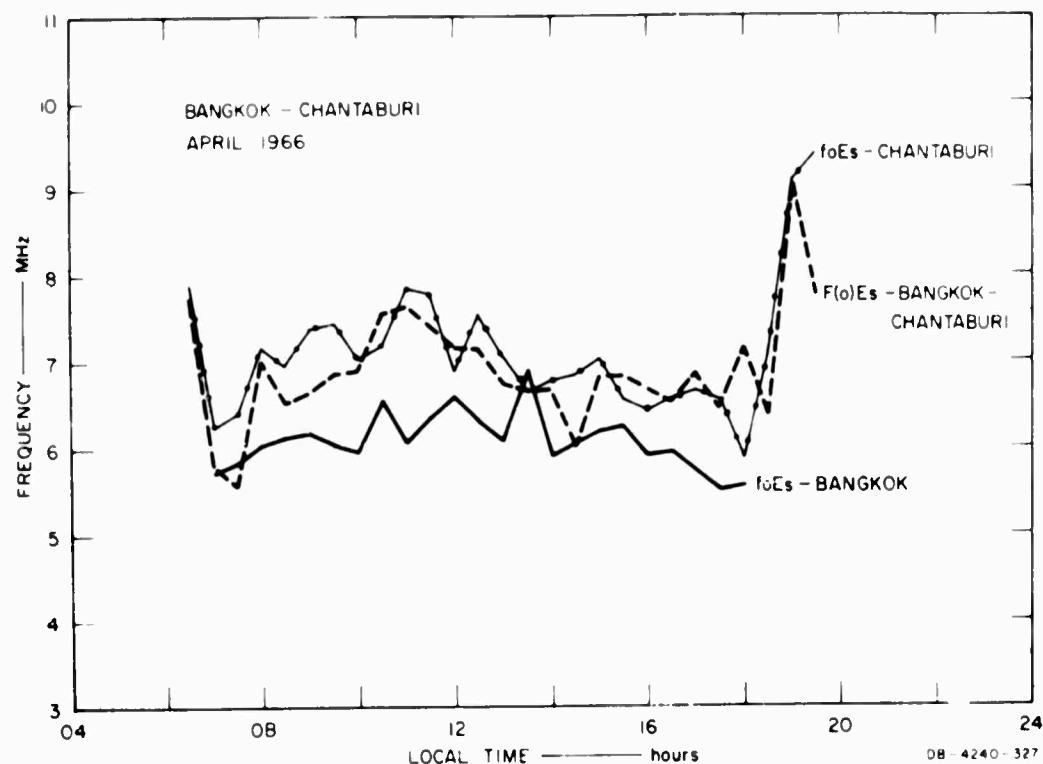


FIG. 17 COMPARISON OF foEs AND MAXIMUM FREQUENCY FOR Es ON OBLIQUE PATH (Bangkok-Chantaburi)

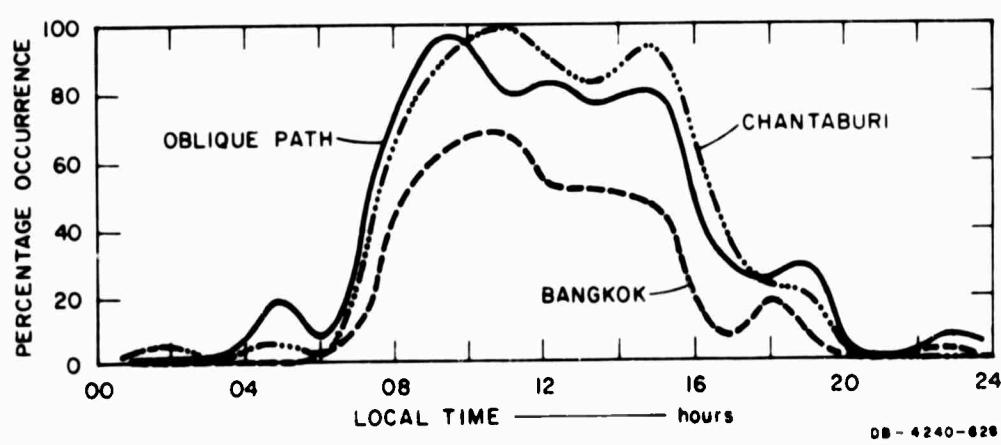


FIG. 18 OCCURRENCE OF Es AT TERMINALS AND ON BANGKOK-CHANTABURI PATH

An interesting test of definition is illustrated by Fig. 19, which shows median values of the MOF on the path between Bangkok and Chantaburi, a group of values equal to 85 percent of the MOF--usually defined as the frequency optimum for traffic (FOT)--and the frequency of maximum multipath occurrence. The curve of frequency of maximum multipath is always close to the FOT and in several cases overlaps it. This shows that a frequency selected to lie a fixed percentage below the maximum observed frequency is not necessarily the frequency for optimum transfer of information,¹⁴ because deterioration of the communication channel due to multipath can occur. Supplementary information in multipath is included in Fig. 20, which shows the maximum time delay of reflected returns as a function of local time.

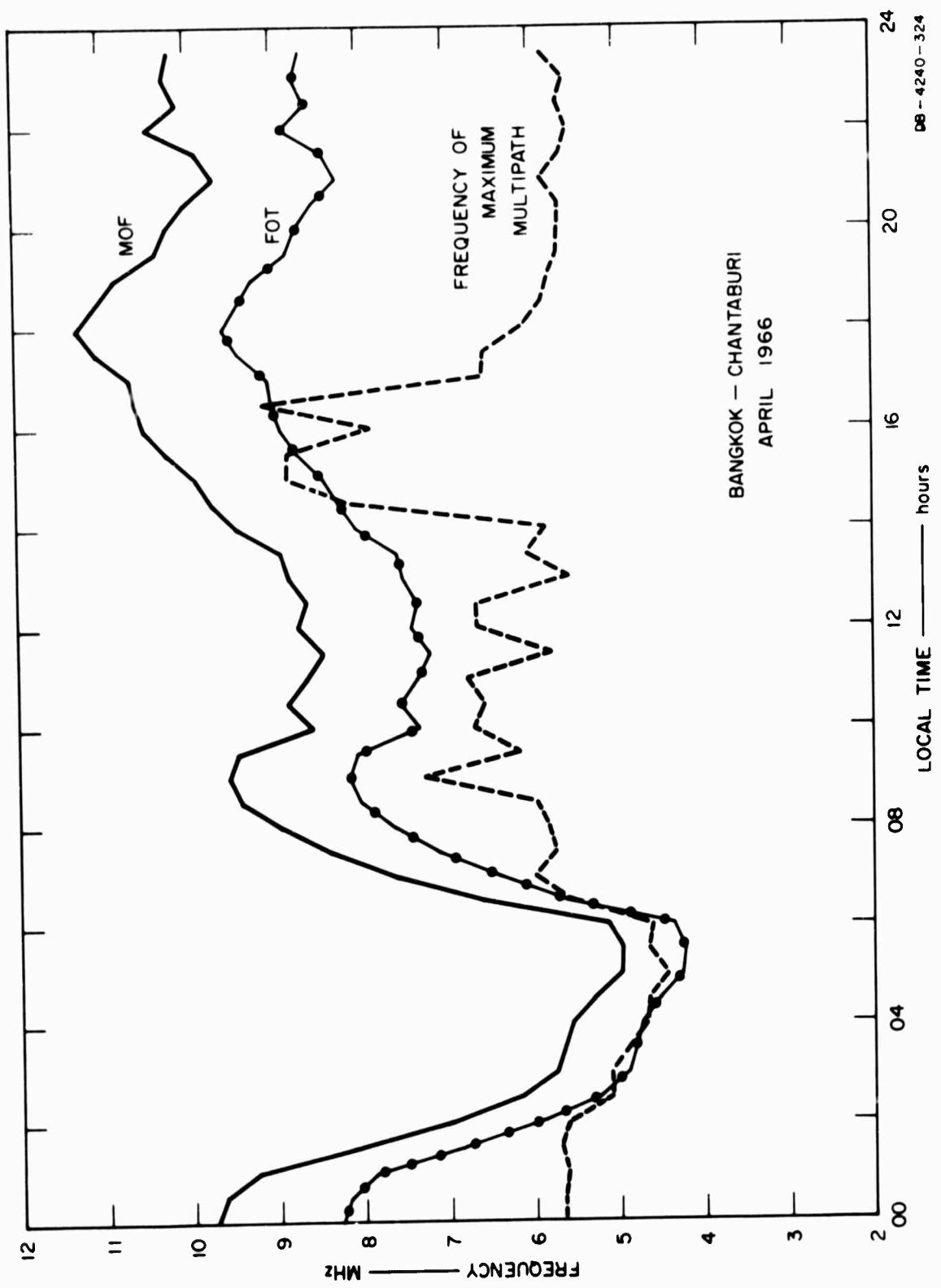
(b) Sounder and Auxiliary CW Measurements on N-S Paths in Thailand

(1) Introduction

A major experiment using the Granger sounders in a program for mapping the ionosphere over Thailand was started during the previous period.¹⁵ The purpose of this study is to provide data and the resulting understanding necessary to improve frequency prediction for HF skywave communication. In addition to operating the Granger sounders to obtain vertical incidence and oblique path ionospheric data, experiments were carried out using a CW signal to gather data on ionospheric path loss and ionospheric stability. Radio teletype equipment was operated in parallel with the sounder and CW experiments to measure performance during the day and night and to relate it to ionospheric conditions. In the previous period, the sounder and auxiliary experiments were performed with the equipments located at Prachuab and Nakon Sawan, Thailand, which lie approximately 220 km south and north of Bangkok respectively (see map, Fig. 21).

(2) Results of Auxiliary Experiments on Nakon Sawan-Prachuab Path

In one of the CW experiments that was run in parallel with the sounder measurements, a 5843-kHz signal was transmitted by a NE-SW oriented dipole from Nakon Sawan to Prachuab, where the amplitude



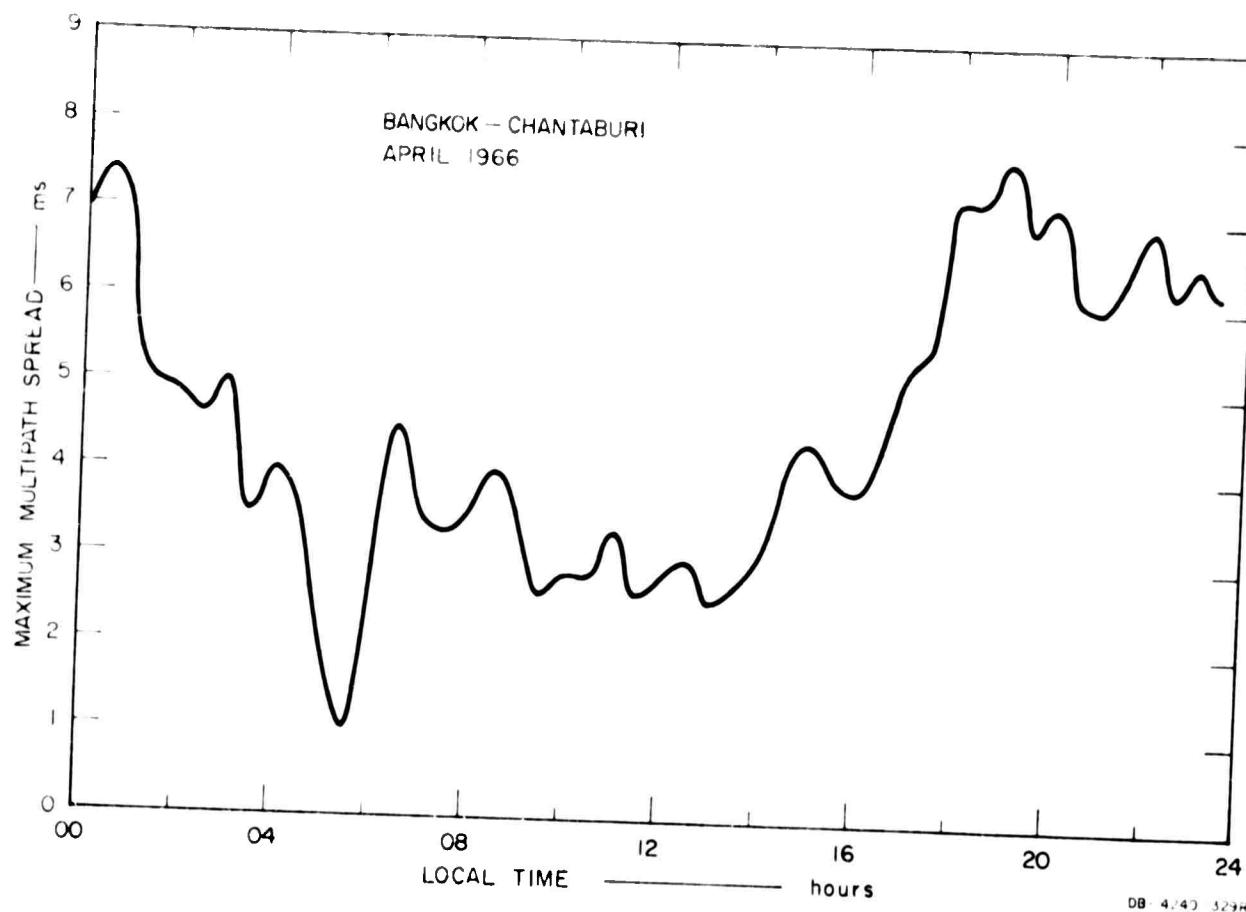


FIG. 20 MAXIMUM TIME SPREAD AS A FUNCTION OF LOCAL TIME
FOR BANGKOK-CHANTABURI PATH

of the signals received on orthogonal dipoles (one oriented N-S, the other E-W) and the correlation of the fading of these two signals was measured. The median envelope correlation of the fading patterns for a period of four weeks (9 July to 5 August) is shown in Fig. 22. This figure illustrates that there is little correlation between the fading patterns except during the period between 1000 and 1400 hours corresponding to the time of day when Sporadic E is prevalent (see Fig. 18). A measure of the ionospheric layer stability in terms of Doppler spread is found in Fig. 23, which shows that the greatest instability occurs when spread F conditions are likely to be present (see Ref. 13). The magnitude of the signal received on the dipoles used on the correlation measurements is shown

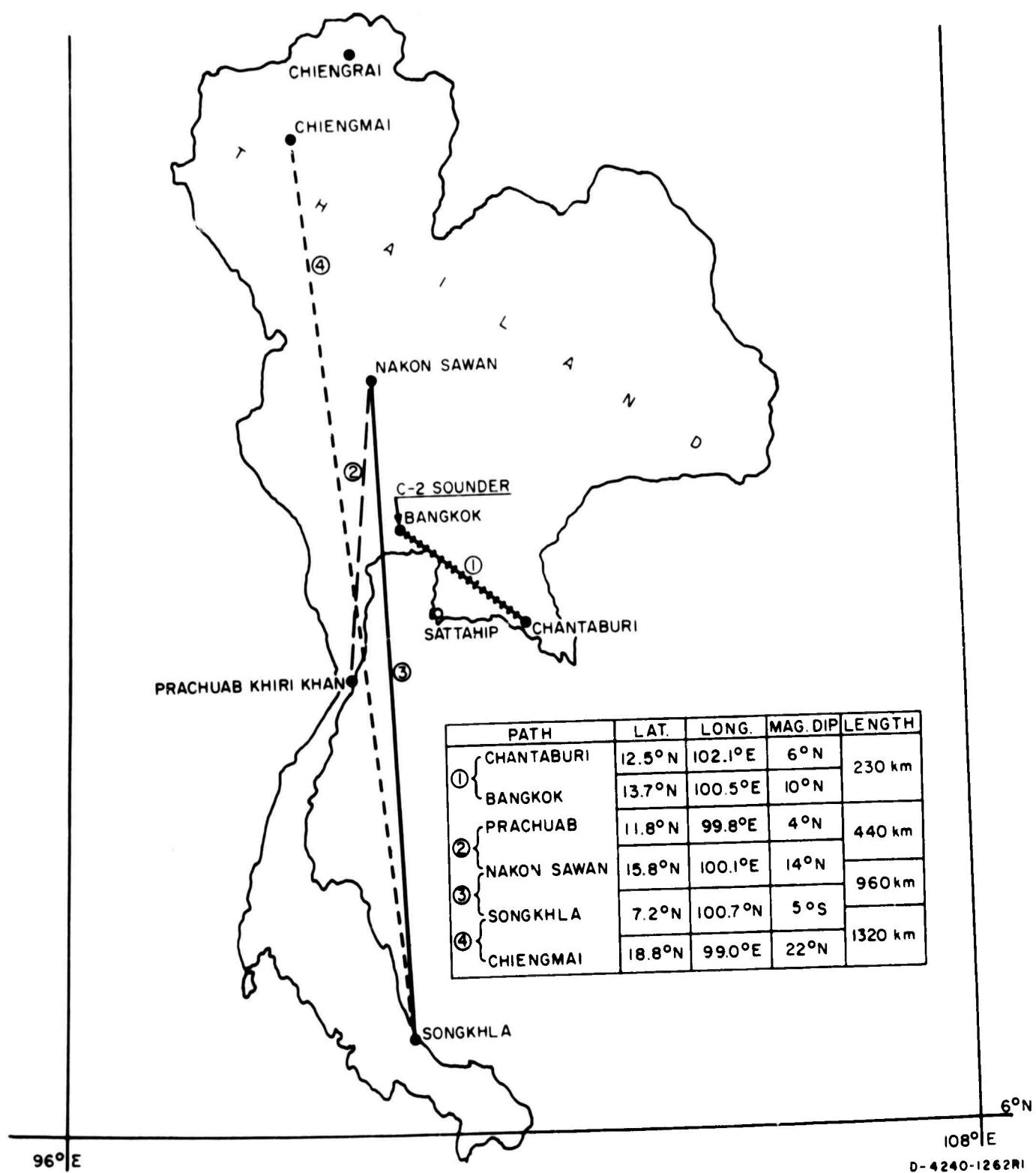


FIG. 21 MAP OF SOUNDER SITES IN THAILAND

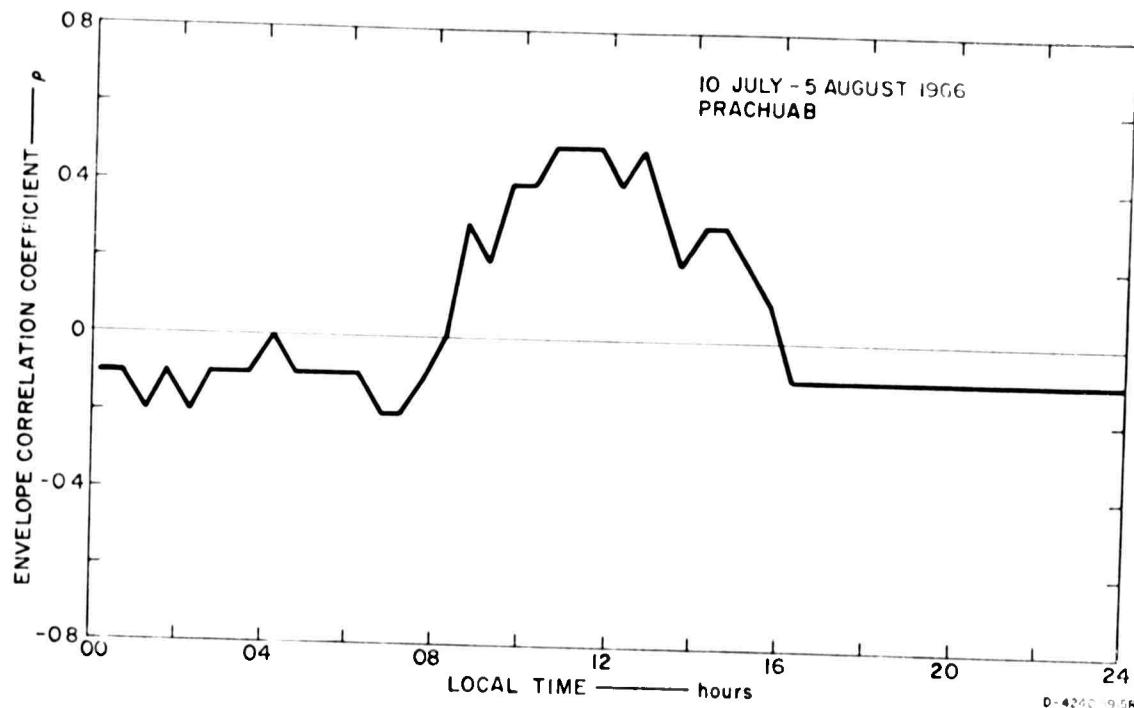


FIG. 22 ENVELOPE CORRELATION OF SIGNAL FADING ON NAKON SAWAN-PRACHUAB PATH

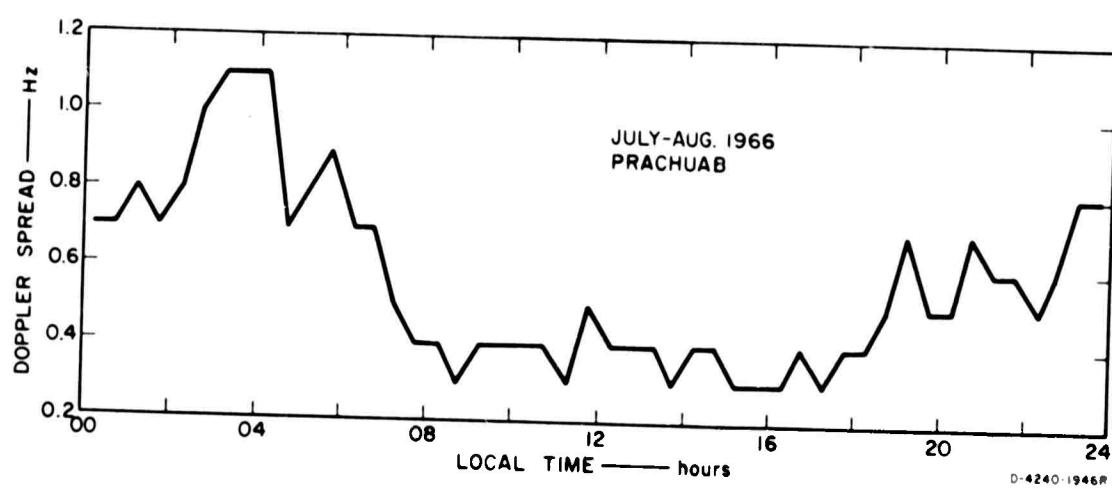


FIG. 23 DOPPLER SPREAD OF 5843-kHz SIGNAL AS A FUNCTION OF LOCAL TIME

in Fig. 24 as a function of time of day for the period of the experiment. The signal is quite strong in late evening, at midnight, and morning; however, it is much weaker in the few hours before sunrise and again at noon. The broad minimum centered at noon indicates increased ionospheric absorption.

The reliability of a radio teletype transmission at 60 wpm as a function of local time is illustrated in Fig. 25, which shows the percentage of received characters containing one or more errors. The peak of errors occurs during the interval when the signal strength is low and the spread F conditions are maximum. Time-delay spreads at 3.8 MHz were only about half those shown in Fig. 20 for the shorter path. Preliminary analysis of the data indicates that low signal-to-noise ratio, rather than large Doppler or time-delay spreads, is the factor controlling the teletype error rate. Since initial measurements indicated a very low error rate during the day and a high rate at night, substantial data were collected only during the period 2000 to 0700.

(3) Further Sounder Measurements on N-S Paths in Thailand

In late September 1966, the sounder at Prachuap was moved to Songkhla and measurements were made on a path between Songkhla and Nakhon Sawan until the middle of November, when the Nakhon Sawan site was dismantled and its equipment moved to Chiangmai (see Fig. 21). The sounders were operated on the Chiangmai-Songkhla path from early December until the middle of March 1967. Vertical-incidence data on both paths were obtained at the terminals and oblique-path data were obtained for transmissions in both directions between the terminal sites. Continuous good data spanning at least four weeks were obtained for both vertical and oblique measurements for both paths, in addition to smaller quantities of valid data obtained between periods of equipment problems. Sounder equipment failure, mostly in the power amplifier section, and much diesel generator trouble, caused significant down time. The ionograms obtained during these experiments were sent to Menlo Park for processing and scaling, which has not yet been completed.

The Songkhla sounder site is shown in Fig. 26. The Granger sounder is housed in the van in the foreground, and the transmitter for the CW experiment, the receiving system for the S66 transmissions and a magnetometer are housed in the S141 shelter that sits beyond the sounder

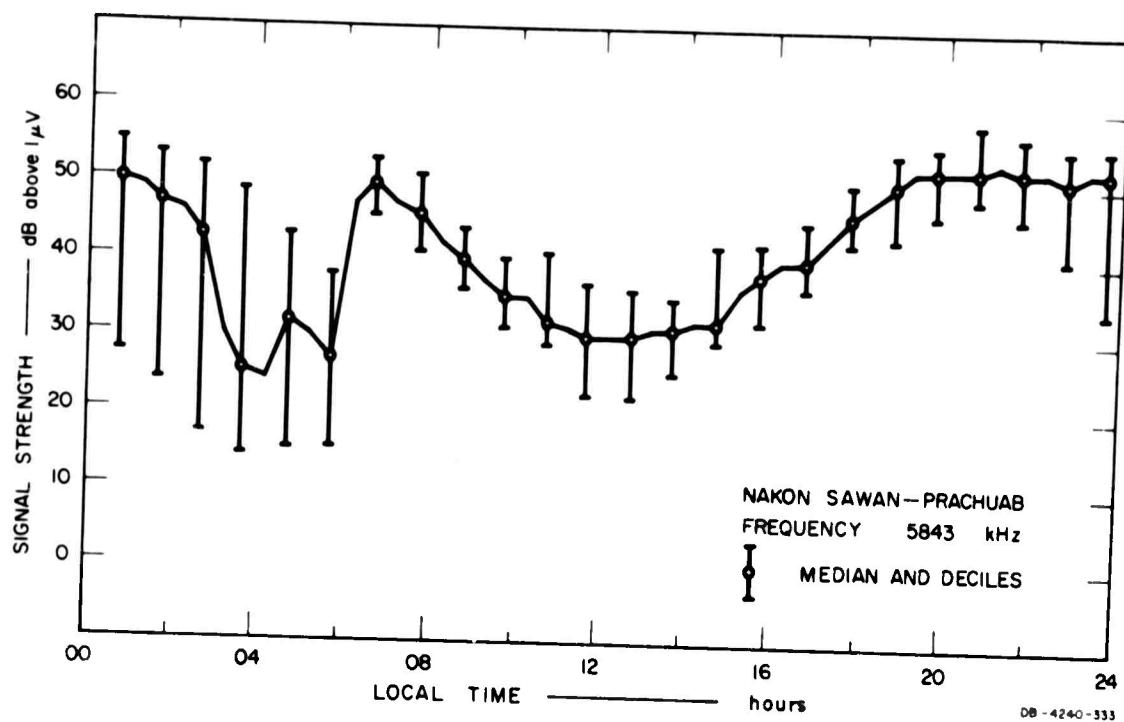


FIG. 24 STRENGTH OF 5843-kHz SIGNAL AS A FUNCTION OF LOCAL TIME

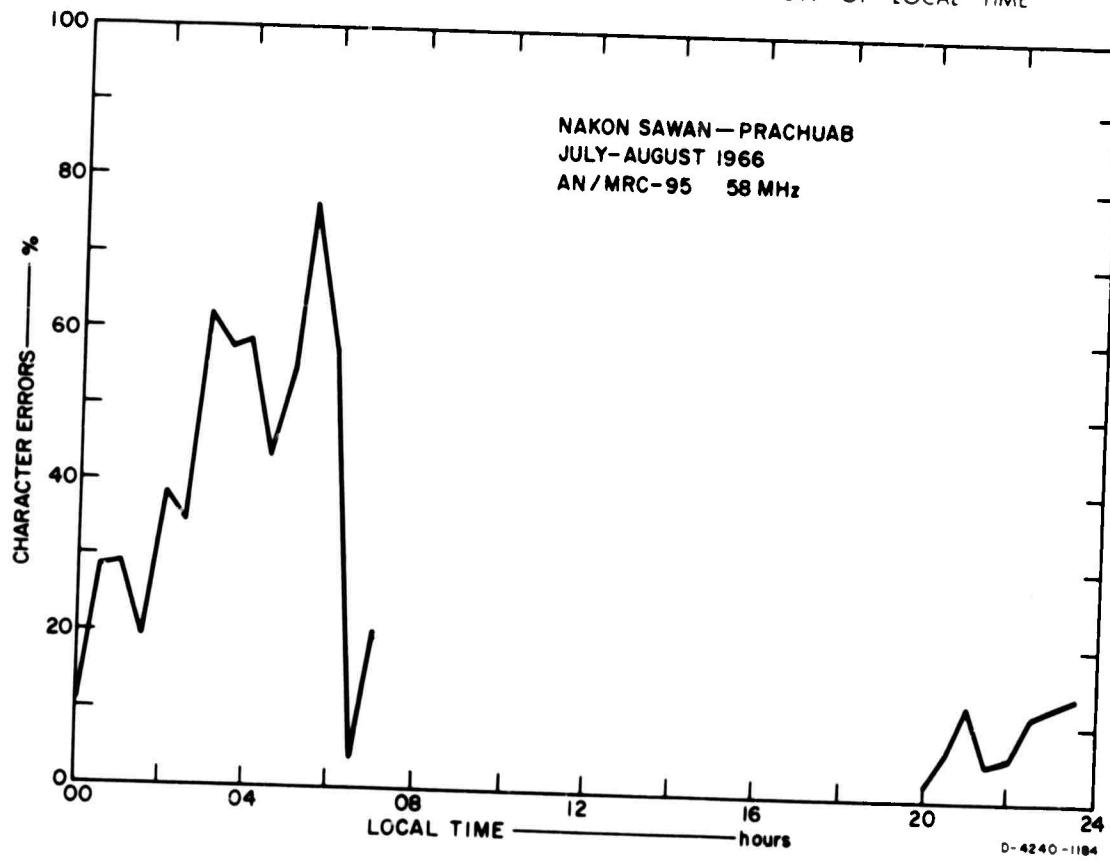


FIG. 25 RADIO TELETYPE ERRORS AS A FUNCTION OF LOCAL TIME

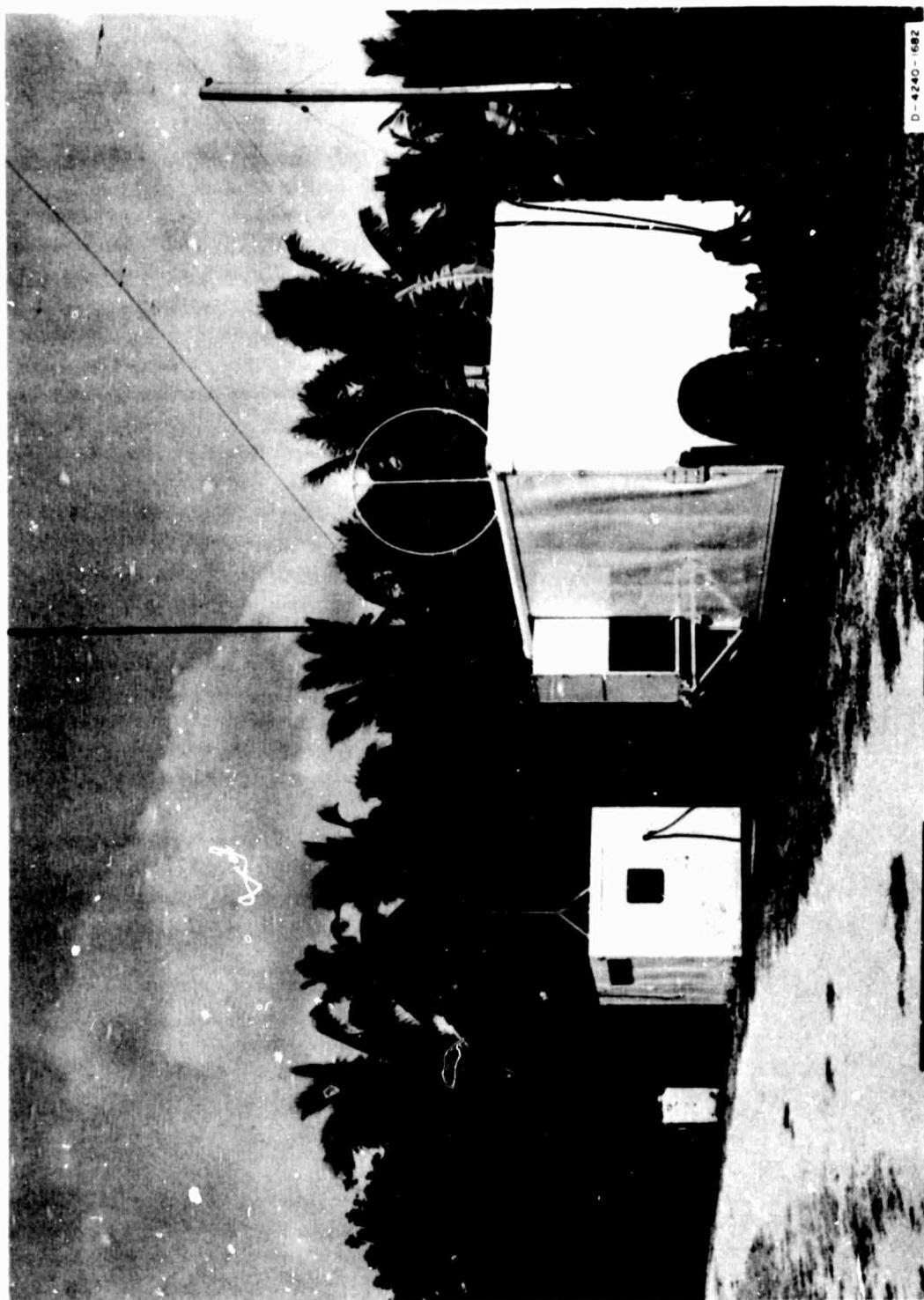


FIG. 26 EQUIPMENT VANS AT SONGKHLA SITE

van. The antenna on top of this shelter is for receiving the 41-MHz satellite signals. The log periodic antenna used for both vertical and oblique incidence sounding is shown in Fig. 27. It will be observed that the bottom of the antenna curtain was raised to about 18 ft above ground. This change was necessary to improve the low-frequency performance of the antenna on the long oblique paths between Songkhla and Nakon Sawan and Songkhla and Chiengmai. The vertical radiation pattern of this antenna is broad enough that the quality of the vertical incidence ionograms did

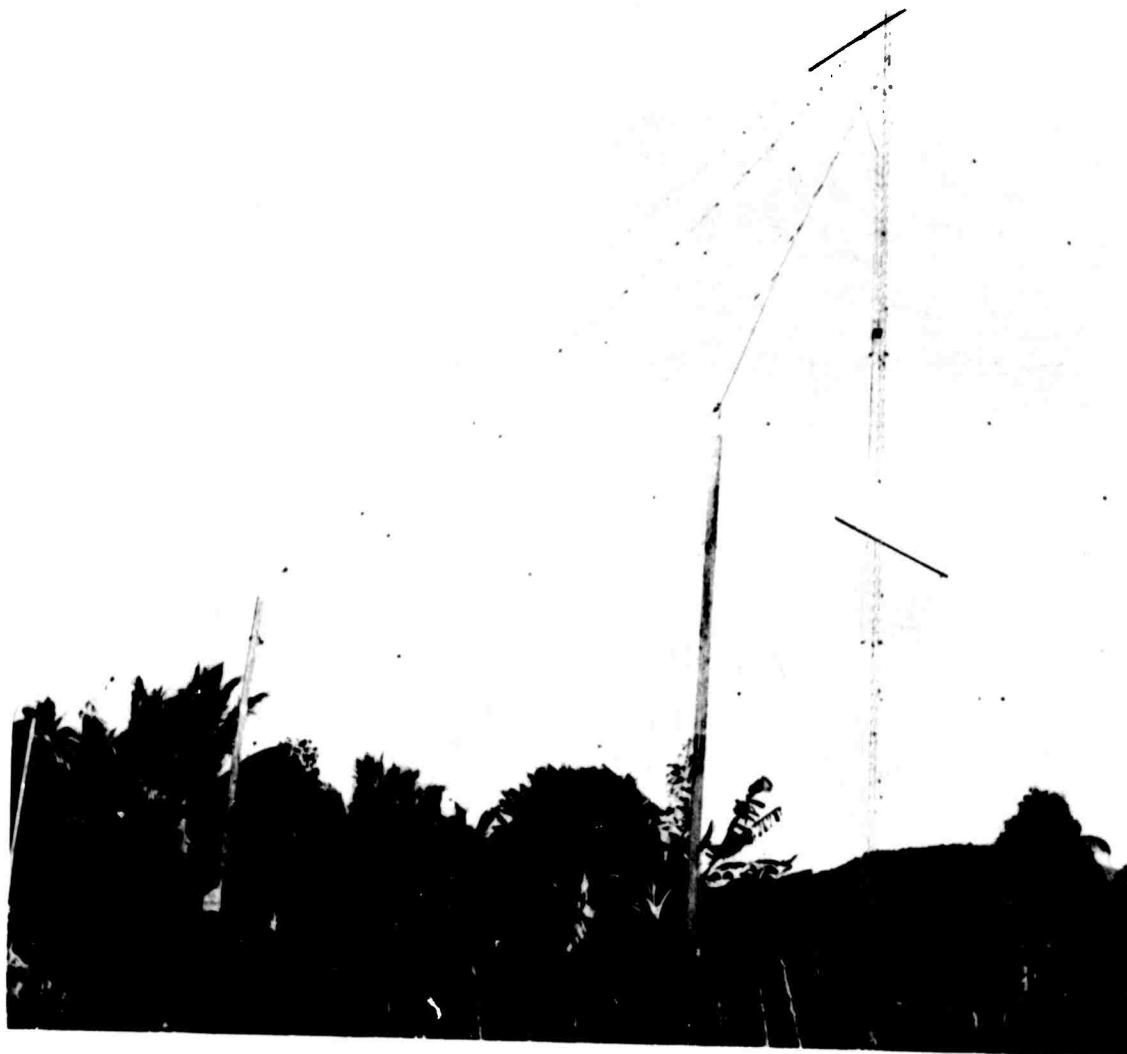


FIG. 27 LP ANTENNA AT SONGKHLA SITE

not suffer appreciably. In the previous experiments where the distance between sounder sites did not exceed about 400 km, the LPA operated successfully when the lower end of the antenna array was only a few feet above ground.

(4) Continued Auxiliary Experiments to Supplement the N-S Sounder Tests

Auxiliary experiments were continued to gather data to supplement the results of the ionospheric soundings. A CW signal was transmitted from Songkhla to Nakon Sawan, where the signals were received on an E-W and a N-S dipole and recorded, and the correlation between the fading of the two signals was measured by the SRI correlation computer.¹⁶ The signal received from the N-S antenna was also applied to the Doppler spread meter to record the dispersion of power in the CW signal due to ionospheric instability. For these experiments a test frequency of 5843 kHz was used. In an additional experiment, an AN/MRC-95 radio teletype unit transmitted from Songkhla to Nakon Sawan on 5885 kHz. A prescribed test message was transmitted and the received message, which was later scaled for errors, was printed at the Nakon Sawan receiving site. The CW and radio teletype experiments were later carried out on the Songkhla-Chiengmai path, but because of the longer distance, frequencies of 7970 and 8015 kHz were used for the CW and radio teletype respectively. Reduction of the data from these experiments has begun in Bangkok.

(c) Frequency Prediction for 1967

Predictions of monthly medians for the F2 critical frequency at Bangkok for 1967 were generated and submitted to USAECOM for approval as Special Technical Report 28.¹⁷ The predictions were obtained by first generating a set of "standard" predictions from a computer program developed by SRI for the U.S. Army Radio Propagation Agency (RPA) several years ago¹⁸ and applying the correction function to these standard predictions. The correction function was derived from a comparison of SRI/RPA standard predictions for the period of April 1965 through August 1966 with monthly medians of actual measured values at Bangkok obtained by the C2 sounder. The predictions for 1967 show an average increase of about 1 MHz over the 1966 predictions and indicate that in 1967 an operating frequency up to 8 MHz

during the daytime with a minimum of 3 MHz just before sunrise can be selected as a conservative estimate for the vicinity of Bangkok.

In the study that produced the 1967 predictions, the effectiveness of similar corrections to predictions for the period 1965-66 was evaluated. The generation of these correction functions goes back to still earlier work¹⁹ in which predictions for the period September 1963 through March 1965 obtained from the SRI/RPA computer program and from world-wide maps prepared by the National Bureau of Standards* (NBS)²⁰ were compared with C2 measured values obtained at Bangkok. The comparison of the resulting corrected SRI/RPA and NBS predictions for 1965-66 with the medians of actual measured values at Bangkok showed that for both methods of prediction the corrected predictions were more accurate than the standard predictions. Figure 28 shows the degree of improvement of the corrected predictions relative to the standard and also illustrates that the corrected NBS prediction is more accurate than the corrected SRI/RPA prediction.

As a result of this evaluation, it was recognized that corrected predictions for 1967, based on NBS world maps, would be very desirable. However, the NBS computer program for the standard predictions was modified²¹ starting with the January 1967 predictions and therefore a correction function based on comparison of 1965-66 data cannot be applied with confidence to 1967 predictions.

(d) Faraday Rotation Experiments

Recordings from the Beacon satellite S66 were made on 40 and 41 MHz during the day and night at the Bangkok Laboratory throughout this period. Recording on 20 MHz at night was discontinued because usable records could not be obtained because of low 20-MHz signal strength and considerable interference. The recording and control equipment continued to operate reliably and more than 85 percent of the fading records show

* The Central Radio Propagation Laboratory of the National Bureau of Standards, Boulder, Colorado--now called the Environmental Science Services Administration (ESSA) of the Institute of Telecommunication Sciences and Aeronomy (ITSA), U.S. Dept. of Commerce.

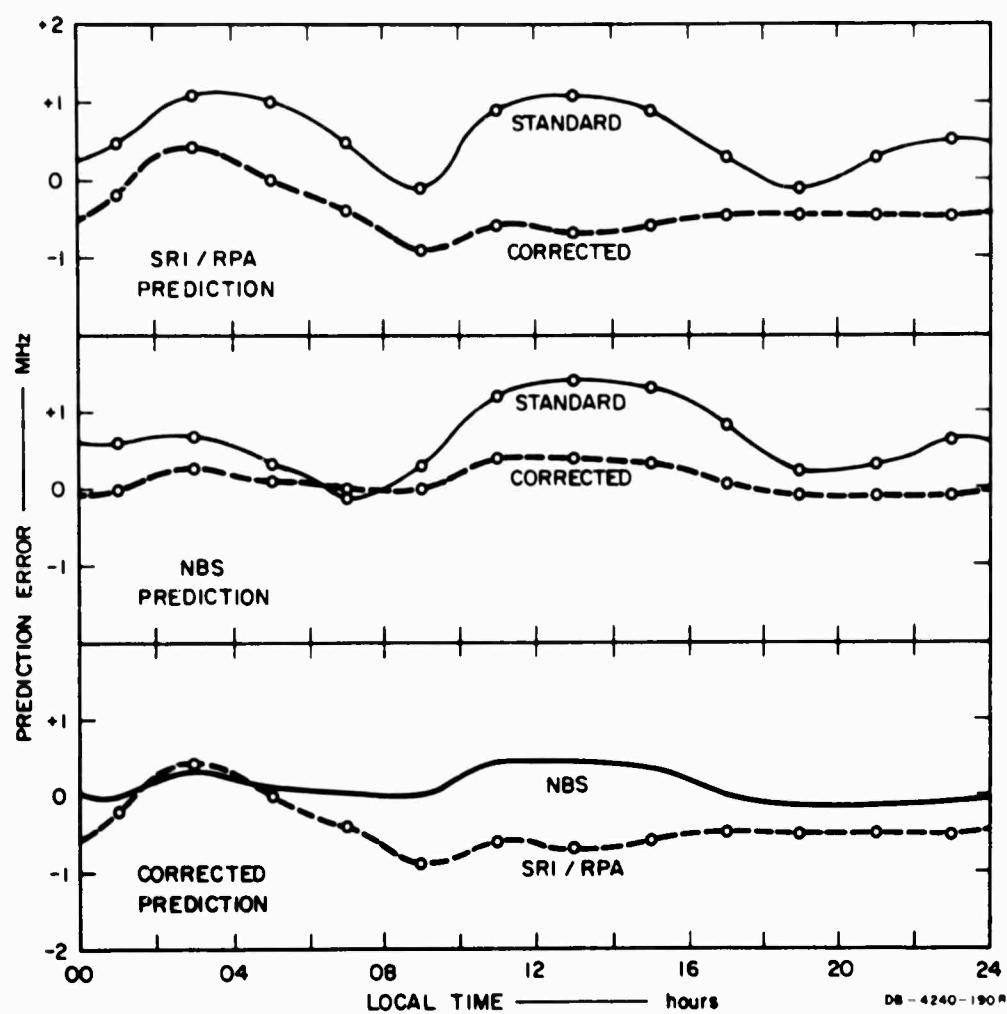


FIG. 28 ERROR IN foF_2 PREDICTIONS FOR BANGKOK

the transverse position (T_o) required for reducing the data. Data reduction continued on a current basis and a Faraday rotation bulletin²² for the period of July-December 1966 was published. The plot of total electron content against local time taken from this bulletin is shown in Fig. 29. A secondary maximum of electron content occurred near midnight in early November (see ascending data) and to a much smaller extent early in August (descending data). The secondary maximum was also observed during May 1966.²³ Private communications with members of the Physics Department at the University of Hong Kong disclose that these effects have also been observed at that laboratory.

A 41-MHz satellite receiving station operated day and night at the Songkhla field site from September 1966 until the middle of March

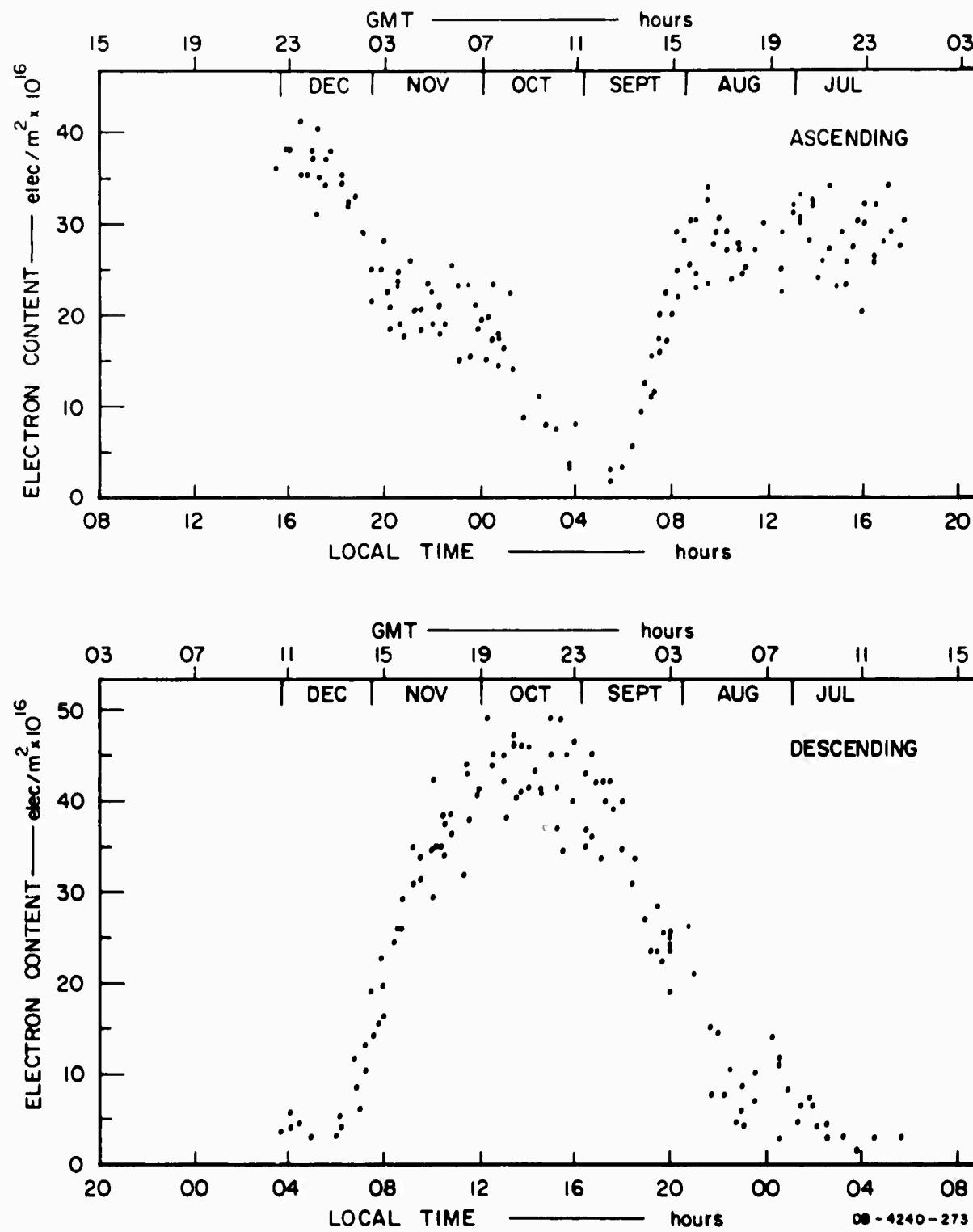


FIG. 29 ELECTRON CONTENT FOR FARADAY ROTATION DATA

1967. A similar receiving station was operated at Nakon Sawan during October, November 1966 and at Chiengmai from December to mid-March 1967. Data from these field sites have been partially reduced, but the actual calculation of electron content depends upon a set of G constants, which is still being calculated. Considerable progress has been made in the programming of the mathematical equations for the calculation of these constants and the entire job will be completed early in the next period. Having detailed values of these constants for the range of latitude between Songkhla and Chiengmai will make possible the calculation of electron content by the simple analysis method at each of the remote sites. In addition, by means of the full analysis, the variation of electron content as a function of latitude may be obtained over a range of approximately 22 degrees, centered at Bangkok.

Data collected for calculating electron content of the ionosphere by the Faraday rotation technique have been used to calculate the magnetic dip angle at ionospheric heights. This calculation is based on accurate knowledge of the time, T_0 , when the signal ray path is orthogonal to the earth's magnetic field. This time is read from the chart recordings (Fig. 30) and the satellite position at this time is derived from the satellite ephemeris.²⁴ When the locations of the satellite and the receiving station are known and the rotation effect is assumed to be localized at a height corresponding to the centroid of the electron density profile, calculation of the dip angle becomes a problem of geometry. Magnetic dip angle for each station was calculated* from the transverse position (T_0) data collected at satellite receiving stations in Songkhla, Prachuab, Bangkok, Nakon Sawan, and Chiengmai. The results are shown in Fig 31, which also includes values of surface magnetic dip angle measured by the Geodesy Department, Ministry of Defense, Thailand.

* The actual calculation was made for the latitude of the subionospheric point (the projection on the earth of the intersection of the ray path between the satellite and ground station with the centroid of the ionospheric electron density profile). The subionospheric point is slightly north of the ground stations for stations north of the dip equator, and slightly south for stations south of the dip equator. Extrapolation of the results from these stations (north and south of the dip equator), as a function of latitude (Fig. 31), places the magnetic equator very near 9.3 degrees N geographic latitude for this area, regardless of whether the surface or ionospheric data are used.

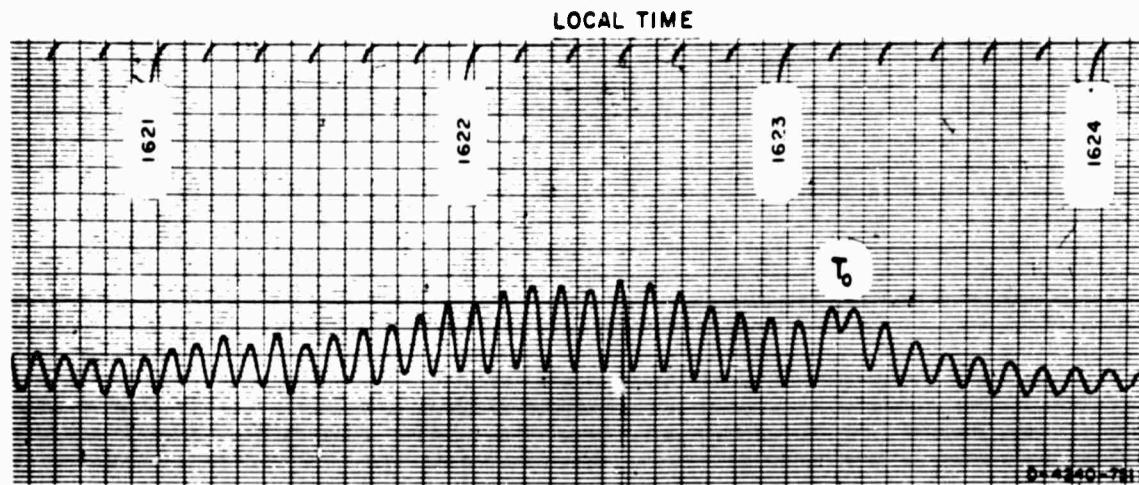


FIG. 30 FARADAY ROTATION FADING RECORD

The close agreement of the two sets of data indicate that the dip angle at ionospheric height is very close to the surface value in Thailand.

(e) Magnetometer Results

The Varian rubidium vapor magnetometer was operated at the Bangkok laboratory throughout this reporting period, and a second unit was operated at the Songkhla field site for about 90 percent of the time. For quiet days, diurnal variations of magnetic field strength as high as about 100-110γ at Songkhla and about 40-50γ at Bangkok were observed. Several severe magnetic storms were recorded. Following the magnetic disturbance of 16 February 1967 the ionospheric absorption near noon was abnormally high for about 10 days. In the other cases of magnetic disturbances however, no corresponding ionospheric effects were observed.

(f) Atmospheric Radio Noise Measurements

The ARN-3 noise measuring equipment was operated at the Laem Chabang low man-made noise site, and two parameters of atmospheric noise--the mean noise power, F_a , and the mean deviation of envelope voltage from the average power, V_d --were measured on a continuous basis throughout the period at 0.53, 2.3, 5.0, and 10.0 MHz. In November

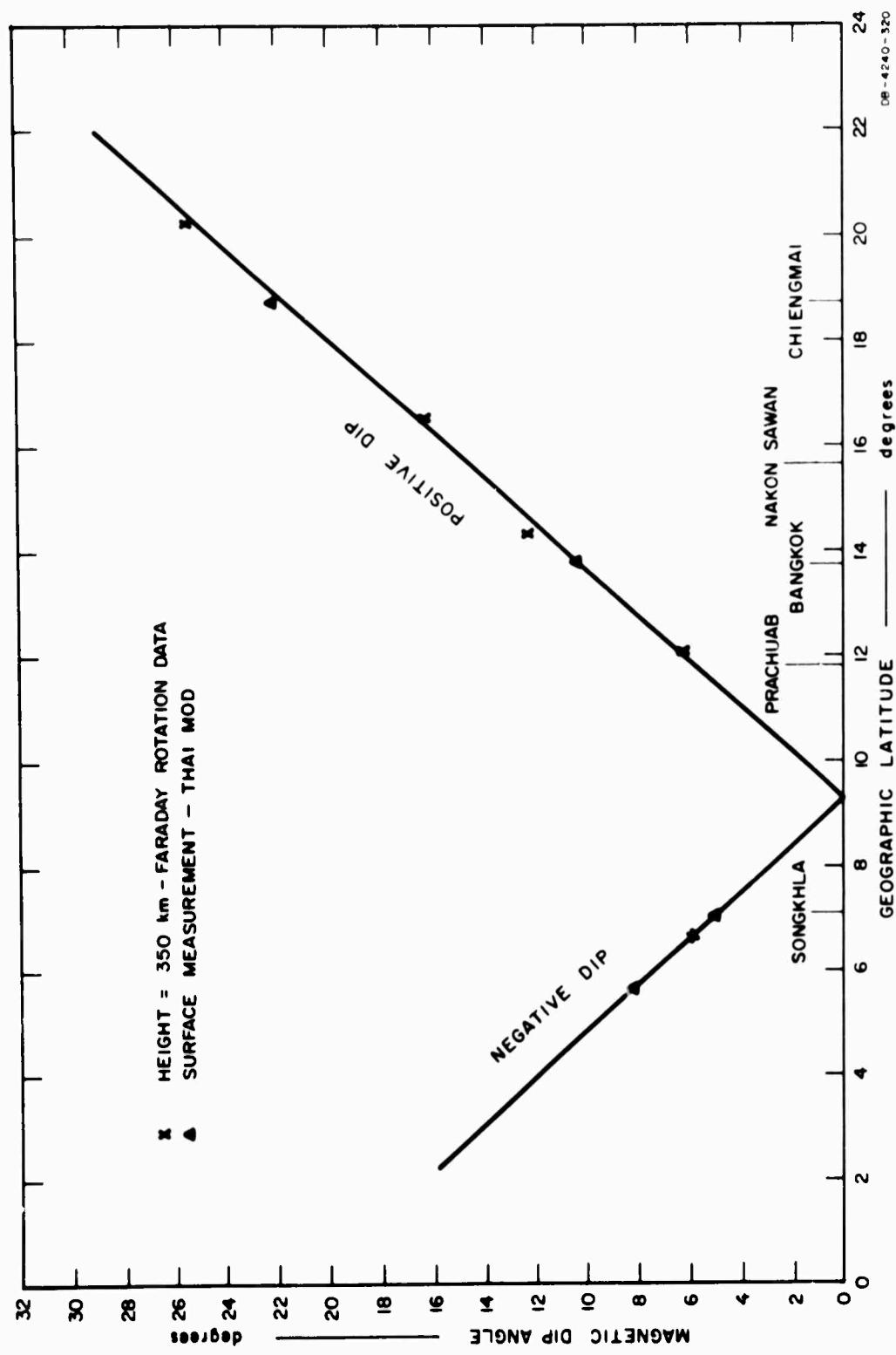


FIG. 31 MAGNETIC DIP ANGLE AS A FUNCTION OF LATITUDE

the VLF converters were put into operation and measurement of noise at 3, 10, 27, and 160 kHz was initiated. The two lowest frequencies were later changed to 6 and 13 kHz to give a better balance of measuring frequencies. Noise data bulletins containing information on the four MF and HF frequencies for the March-April-May and June-July-August quarters of 1966 were prepared and the format was submitted to USAECOM for approval.

Operation of the ARN-3 noise measuring equipment at Laem Chabang during the 13 months following 1 March 1966 proved to be quite satisfactory. Calibrations were made weekly and it was found that during the first 50 weeks the average drift from one week to the next ranged from 2 to 3 dB for the four frequencies. This means that the average uncertainty of F_a readings due to drift in the equipment was less than 3 dB for all measured frequencies. A moderate number of component failures was experienced but on the average the measuring equipment was operable more than 75 percent of the time. During the first year of operation (March 1966 through February 1967) the monthly median value of F_a was based on an average of 22 days per month. For 75 percent of the time, 20 days or more were used in calculating the monthly median. The loss of data due to man-made radio interference (QRM) which propagated in did not change significantly from that reported in Semiannual 7.25 The procedure for manually monitoring the equipment for about five hours in the morning and five hours in the evening to keep the recording pens on scale was followed without change. This has proved to be a satisfactory procedure since the operator can adjust the fine tuning of the receiver to avoid QRM in addition to adjusting the series attenuation to keep the pens on scale. Indeed avoiding interference by manual tuning of the receiver while listening is essential to the collection of reliable atmospheric noise data.

Seasonal time-block values of radio noise are given in Fig. 32 for the March through April 1966 quarter and in Fig. 33 for the September through November 1966 quarter. Each point on these curves represents the median of three months data for a four-hour time block. The quarterly median for the 0000 to 0400 time block, for example, is

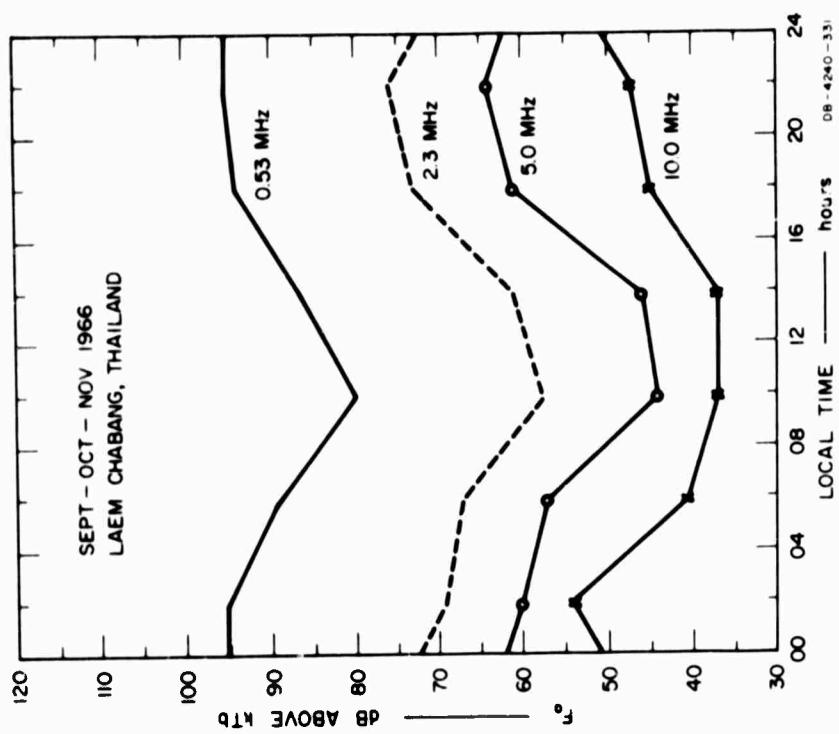


FIG. 33 RADIO NOISE FOR SEPTEMBER NOVEMBER 1966

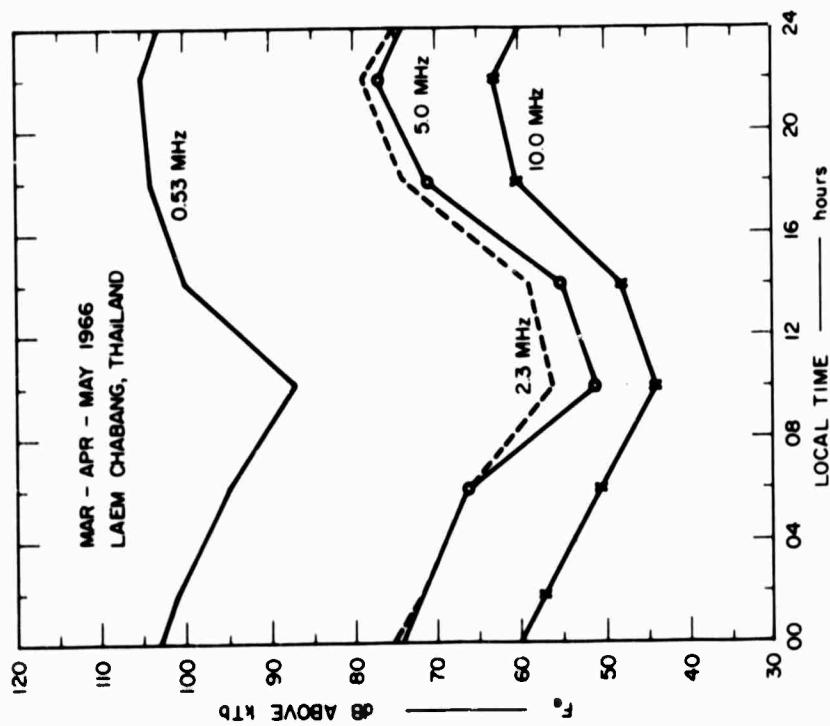


FIG. 32 RADIO NOISE FOR MARCH-MAY 1966

plotted at 0200. The wide dispersion of noise amplitude with frequency between 0.5 and 10 MHz can be seen as well as the characteristic daytime minimum for all frequencies. It will be noted that the spread with frequency is more uniform in the Fall (September, October, and November) data than in the Spring data, and that the magnitude of noise for all frequencies is lower. A comparison of measured noise with that predicted from CCIR noise contour maps for 5 MHz for the Spring quarter is shown in Fig. 34 and a similar comparison for the Fall quarter is shown in Fig. 35. It will be observed that the measured noise is higher than the predicted noise during the spring, but that the agreement between predicted and measured noise in the Fall is excellent. An explanation of the difference in agreement between predicted and measured noise for the two seasons may be the difference in the contribution of local thunderstorms to the ARN-3 readings. The prediction should agree better with measured noise in the absence of local thunderstorms because predictions do not take into account local disturbances. Unfortunately, lightning flash data for Laem Chabang during the Spring months of 1966 are not available because the lightning flash analyzer had not been placed into operation.

Some work was done on the analysis of noise data received from ESSA for the Singapore and New Delhi stations. Figure 36 shows a comparison of noise measured at Laem Chabang with noise measured by ARN-2 equipment at Singapore and New Delhi. There is considerable similarity in magnitude as well as in the shape of diurnal variation from the data from the three measuring stations.

After the portable ARN-3 equipment was returned from the Khon Kaen field site at the end of the previous period, it was checked over carefully and modified to conform with the permanent equipment at Laem Chabang. It was then moved to the Laem Chabang site and set about 200 feet away from the permanent installation. The equipment was checked out thoroughly in the low man-made noise environment and was used to measure noise induced in the standard monopole without a ground plane. Near the end of the period experiments to measure the noise induced in a horizontal dipole were initiated. Four available channels in the portable

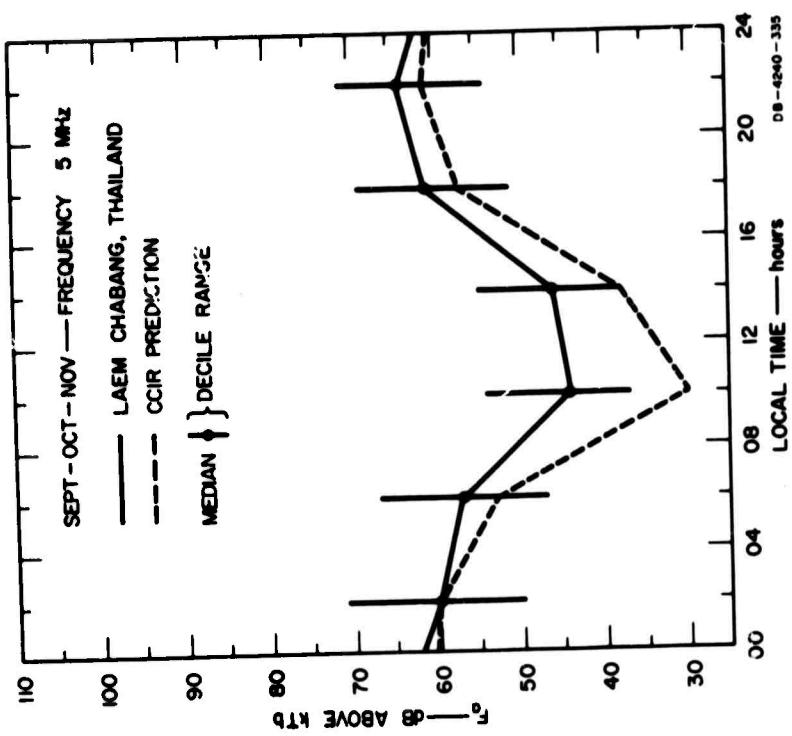


FIG. 35 COMPARISON OF MEASURED AND PREDICTED
NOISE — FALL 1966

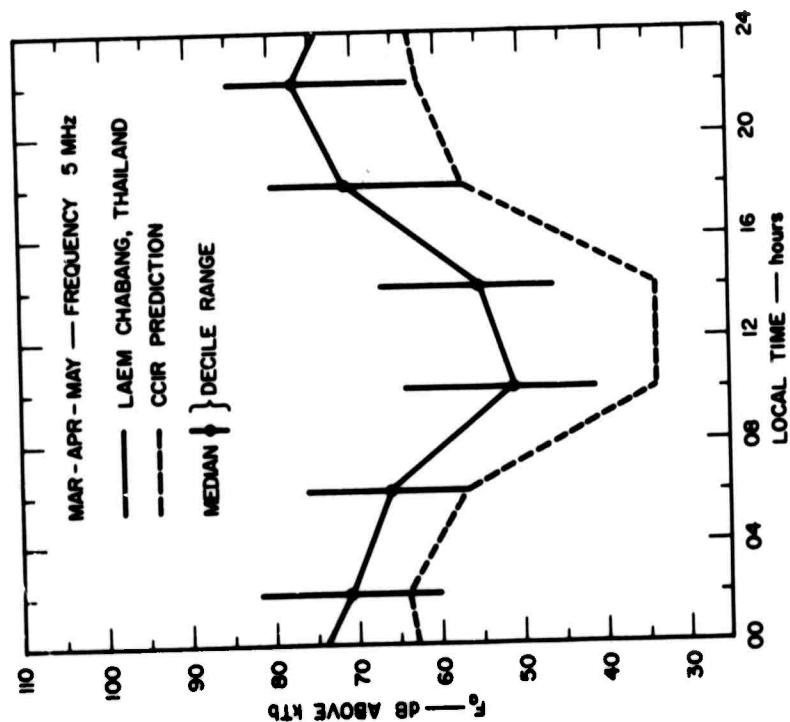


FIG. 34 COMPARISON OF MEASURED AND PREDICTED
NOISE — SPRING 1966

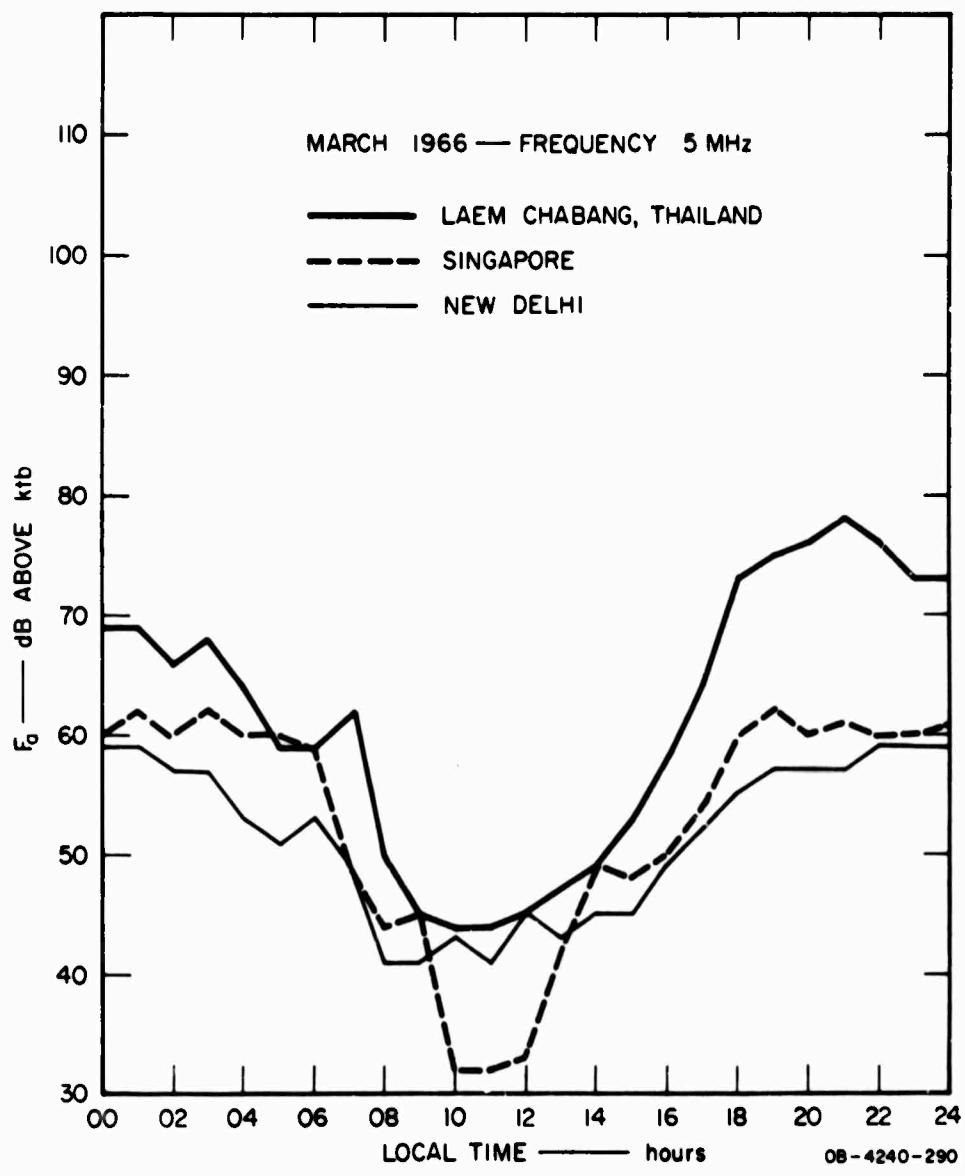


FIG. 36 COMPARISON OF NOISE MEASURED AT THREE STATIONS
IN ASIA

equipment were used as follows: a trapped dipole designed to operate as a tuned half-wave antenna at the frequencies of 2.3, 5.0, and 10.0 MHz was connected through a switch to an input of the measuring set and the receivers were tuned to 2.3, 5, and 10 MHz. This dipole was oriented N-S. A second trapped dipole of identical design was oriented E-W and connected through the switch to the input of the measuring set. The switch was operated automatically each 30 minutes giving alternate recordings on three frequencies of noise from the two dipoles. Two simple half-wave dipoles cut for 2.5 MHz were connected through another switch to the fourth channel of the noise measuring equipment. Noise induced in these dipoles, one oriented N-S in the open and the other N-S immersed in beach foliage was measured on a time-sharing basis on the same schedule as the trapped dipoles.

A comprehensive manual for users of the ARN-3 equipment was prepared and submitted to the sponsor for approval as Special Technical Report 27.²⁶ Excerpts from the manual are shown in Fig. 37, a map illustrating the relationship of Laem Chabang with other key points of Southeast Asia, Fig. 38, a photograph of the equipment installed at Laem Chabang, and Table III which gives a detailed list of specifications of the ARN-3 equipment.

The lightning flash analyzer was operated at the Laem Chabang site throughout this reporting period. Procedures for reducing the data obtained by photographing Veeder-Root counters each half hour were worked out and a standard tabular presentation was adopted. Lightning flash data for September 1966 through February 1967 were tabulated in this form and analysis was begun. An example of recent lightning flash data is shown in Fig. 39 which gives the monthly mean count for December 1966 as a function of local time. Some results of the preliminary analysis of the number of lightning flashes measured as a function of the threshold of the recording equipment are shown in Fig. 40, which compares the mean number of flashes for one month for the CCIR-type equipment at 1, 3 and 10 volt thresholds.

Supplementary information on impulsive noise observed at Laem Chabang is given in Fig. 41 which shows the signal level across the input to a receiving system intended to record the strength of a 20 MHz signal from an orbiting satellite as part of another project which was

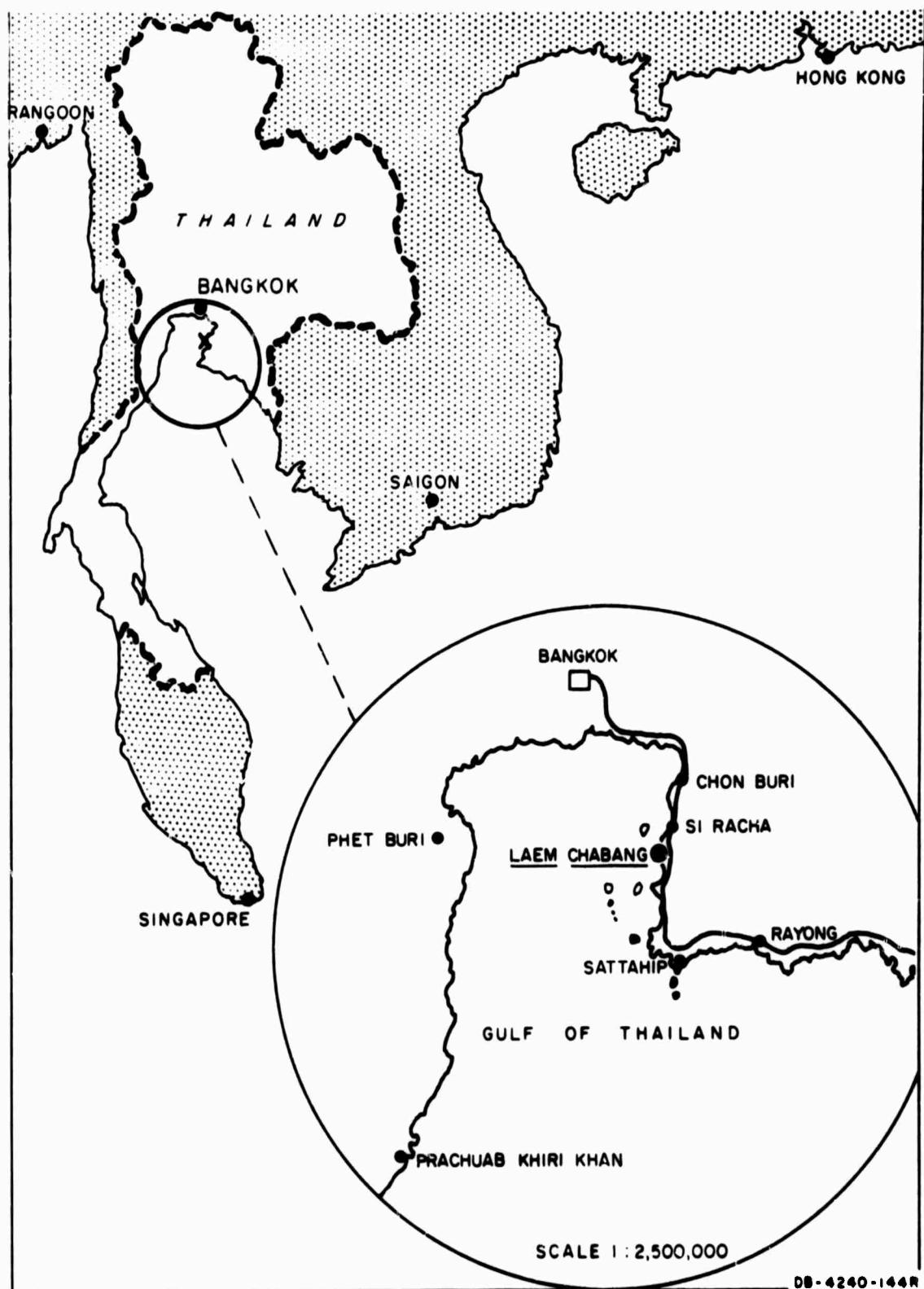
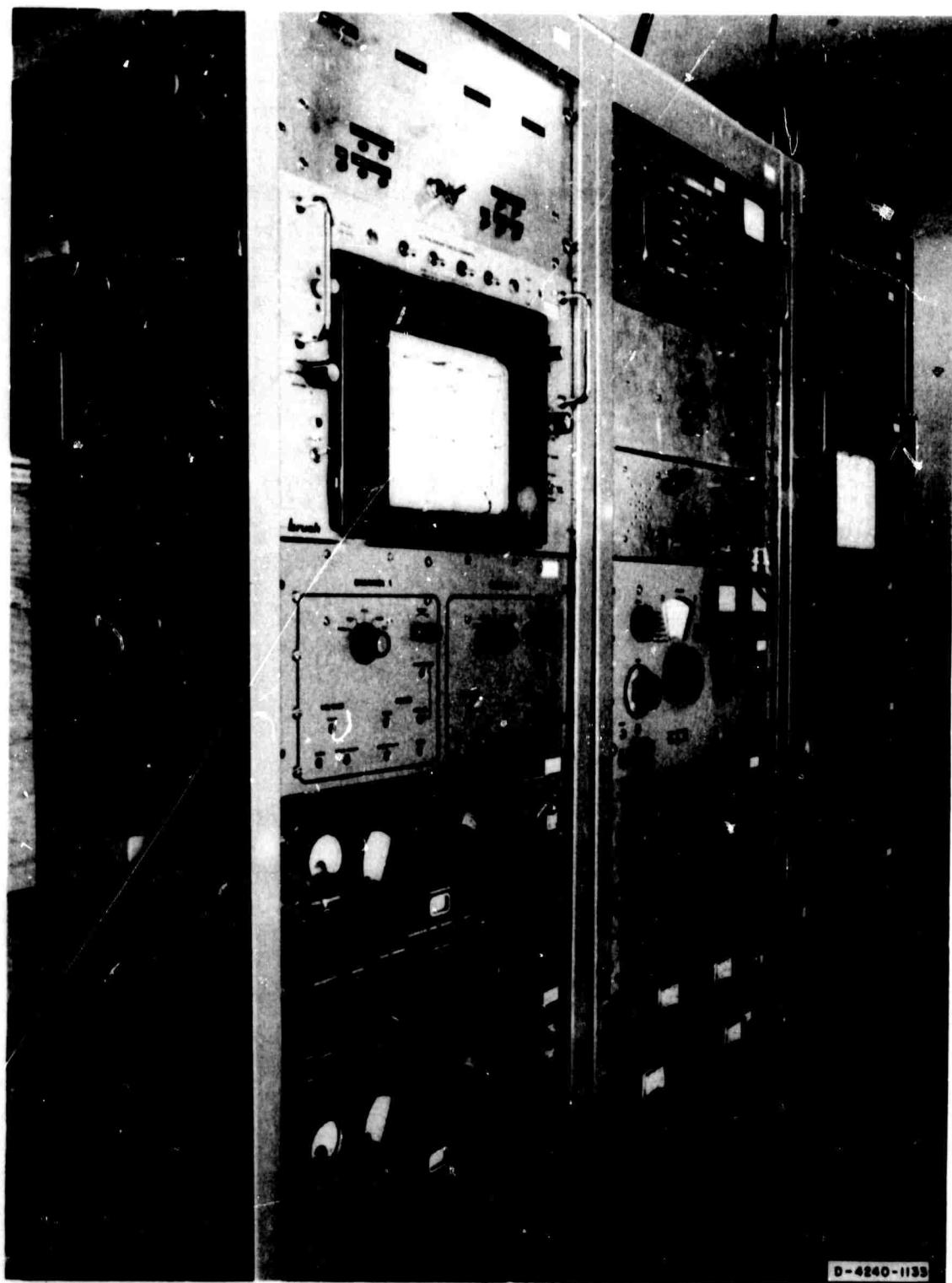


FIG. 37 LOCATION OF LOW MAN-MADE NOISE SITE



D-4240-1133

FIG. 38 LAEM CHABANG INSTALLATION OF ARN-3 EQUIPMENT

Table III
ARN-3 NOISE-MEASURING
EQUIPMENT SPECIFICATIONS

Packaging:	Three standard five-foot relay racks and two seven-foot relay racks.
Power Requirements:	115 V, 60 Hz, 20 A; isolated.
Frequencies:	HF, four channels, each tunable 0.53 to 54 MHz, normally tuned to 0.53, 2.3, 5.0, and 10.0 MHz respectively. LF, four fixed-frequency converters accepting 160, 27, 13, and 6 kHz, respectively.
Band-Pass:	HF, 200 Hz normal operation (adjustable in steps up to 13 kHz). LF, 200 Hz LFA; ERA band 100 Hz to 2500 Hz; CCIR band 2 kHz to 50 kHz.
Sensitivity:	HF, -97 dBm, LF, -46 dBm, LFA, 1 V, 3 V, and 10 V thresholds.
Time Constants:	Power integration, 0.5 s, 5 s, or 500 s. Voltage integration, 0.1 s, 1 s, or 100 s. LFA, 0.6 s dead time.
Dynamic Range:	40 dB (30 dB on chart) plus 70 dB attenuation in 10-dB steps.
Antenna:	21.75-foot telescoping whip, 1.5 inch diameter at base with ground plane consisting of 90 radials of #12 copperweld wire each 100 feet long, equally spaced.
Ambient Temperature:	18 to 24 degrees C, 22 degrees C nominal (65 to 75 degrees F).
Outputs:	Integrated power and voltage in four channels (chart recorded). Count of number of impulses above 1, 3, and 10 V in each of two bands each half hour (photograph).
Timing and Switching:	Internal time standard with power amplifier to drive clocks and recorders. Switching of channels available each 15 minutes or each 30 minutes. Photograph of LFA taken automatically each 30 minutes or each hour.

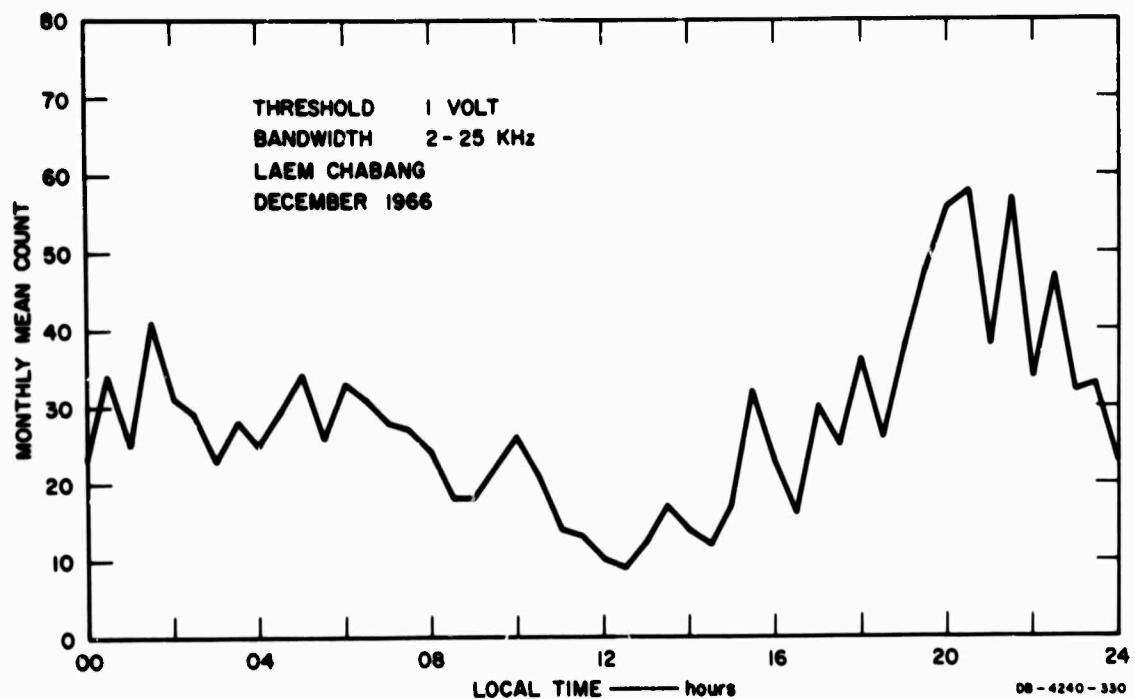


FIG. 39 LIGHTNING FLASH COUNT FOR DECEMBER 1966

sharing the Laem Chabang field site.²⁷ The short interval shown in Fig. 41 occurred at 1000 hours GMT on 2 January 1967. The origin of these impulses is unknown.

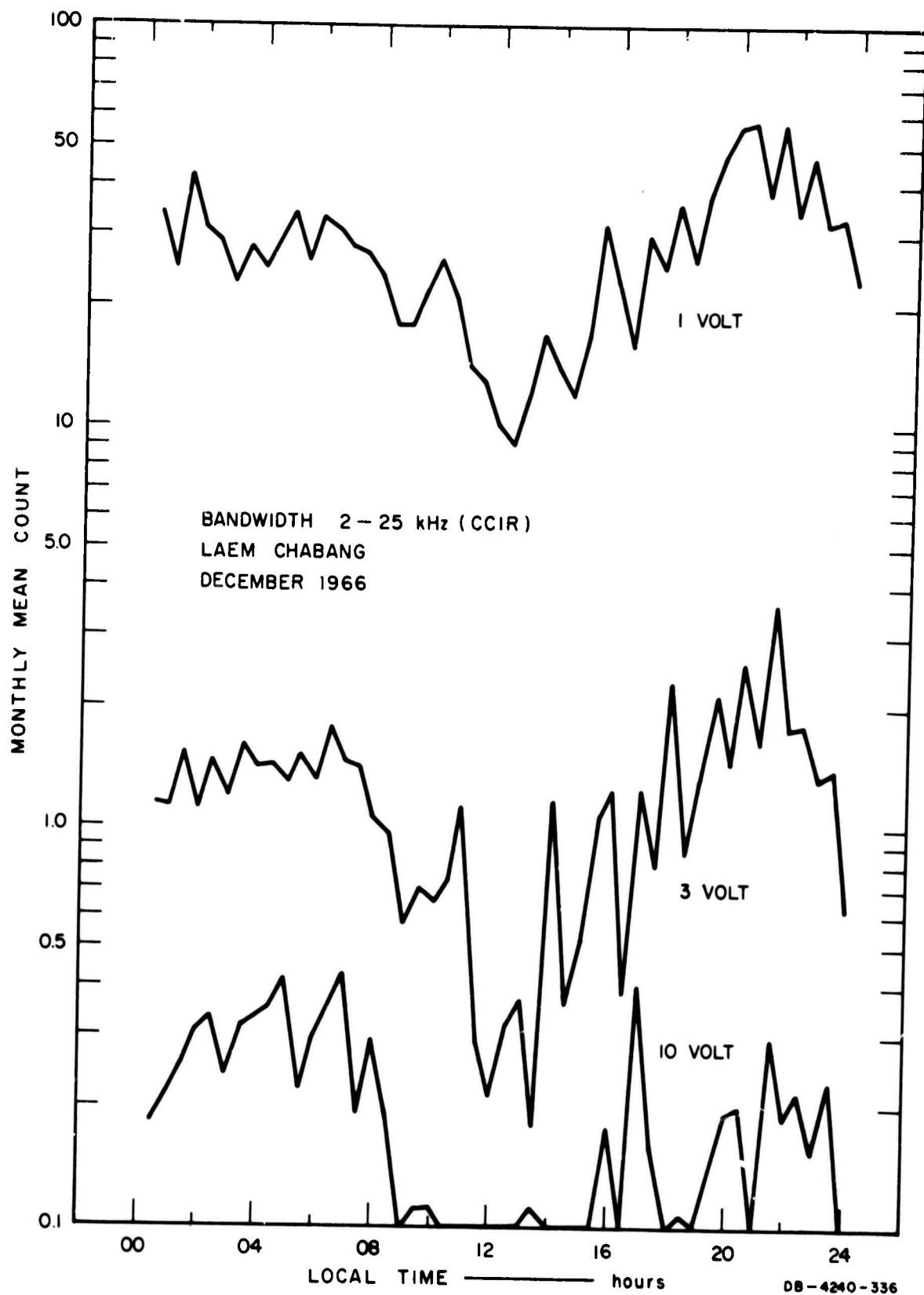


FIG. 40 EFFECT OF THRESHOLD ON LIGHTNING FLASH COUNT

20.75 MHz 2 JANUARY 1967 1000 GMT

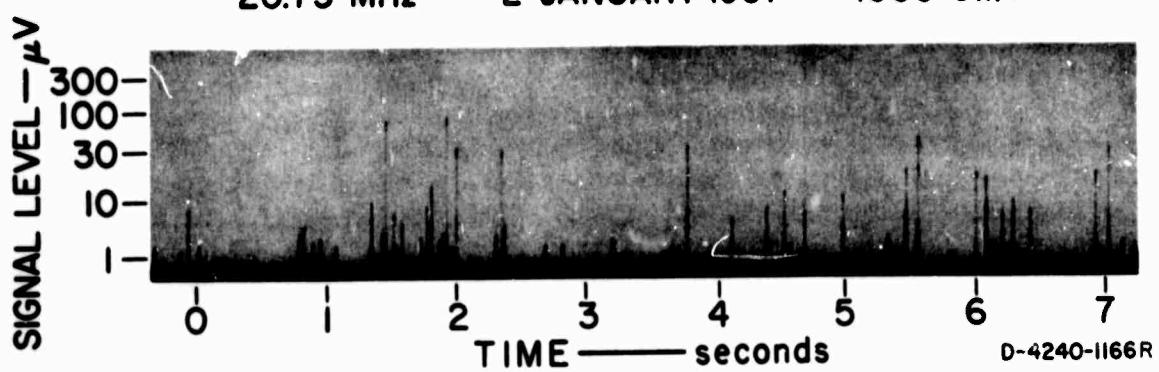


FIG. 41 IMPULSES AT 20 MHz

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